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USING A WHEEL TRACKING MACHINE FOR EVALUATION OF ASPHALT RUTTING

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USING A WHEEL TRACKING MACHINE FOR EVALUATION OF ASPHALT RUTTING

by

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USING A WHEEL TRACKING MACHINE FOR EVALUATION OF ASPHALT RUTTING

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Abstract:

As rutting becomes a major mode of pavement failure in our highways, road agencies affected by the problem will require better laboratory methods to determine and predict mixes with rutting potential. The use of a wheel tracking machine (W.T.M.) has been considered by some jurisdictions as a viable alternative.

This study examines the capability of a W.T.M., recently purchased by the Ministry to evaluate rutting, and its sensitivity to the many variables such as tire style, tire pressure, loading, and number of tracking passes. Test procedures are also developed which take into account the two rutting periods of interest: one immediately after paving construction while pavement temperatures are decreasing and the other, at a constant temperature of 60°C.

In this study, a two layer approach is used. This closely simulates the multi-layer system observed in the field. Both flexible and rigid bottom lifts are evaluated and an H.L.-4 mix using Durham aggregates is considered for use as a standard base for comparative testing.

Both laboratory mixes and field mixes are assessed for rutting potential using the W.T.M. Results show that the W.T.M. is a good tool, capable of producing accelerated rutting under a variety of test conditions and sufficiently sensitive to differentiate rutting mixes. This makes it invaluable in providing data for determining acceptance of mix designs and in studying the effects of various mix parameters with respect to rutting. Hence it is concluded that the wheel tracking machine is a cost effective diagnostic tool which can play an important role in dealing with the problem of rutting in pavements.

Abrégé:

Puisque la formation d'ornières devient un problème de plus en plus important sur nos autoroutes, les organismes responsables devront utiliser de meilleures méthodes en laboratoire afin d'identifier les mélanges qui favorisent cette formation. L'utilisation d'un simulateur d'usure semble être une solution de rechange intéressante.

Cette étude examine la capacité du simulateur acheté récemment par le Ministère à évaluer la formation d'ornières ainsi que sa sensibilité à différents paramètres comme le type de pneu, la pression de gonflage, la charge et le nombre de passages. Nous avons aussi mis au point des procédures d'essai tenant compte de deux périodes précises, soit immédiatement après la pose du revêtement (alors que les températures de ce dernier diminuent) et à une température constante de 60°C.

Notre étude a été basée sur un revêtement à deux couches. Cette méthode imite avec assez de précision les conditions réelles auxquelles est soumis un revêtement multicouches. Nous avons évalué les couches inférieures flexibles et rigides et un mélange H.L.-4 à agrégat minéral a servi de base comparative.

Nous avons ensuite évalué sur simulateur les possibilités de formation d'ornières des mélanges préparés en laboratoire et de ceux préparés sur le terrain. Les résultats démontrent que le simulateur est un bon appareil, capable de former des ornières de manière accélérée sous différentes conditions et qu'il est assez précis pour différencier les mélanges. C'est ce qui en fait un outil inestimable pour récolter des données sur la qualité des mélanges ou encore pour étudier les effets de différents paramètres du mélange sur la formation d'ornières. Nous concluons donc que le simulateur est un outil rentable qui peut jouer un rôle important au niveau des problèmes de formation d'ornières sur les revêtements.

Keywords: Rutting, deformation, permanent strain, asphaltic concrete, laboratory testing, wheel-tracking machine.

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TABLE OF CONTENTS

		Page
1	INTRODUCTION	1
2	BACKGROUND	2
3	PURPOSE AND SCOPE	3
4	WHEEL TRACKING MACHINE	4
	4.1 Machine Components	5
	4.2 Tires	6
	4.2.1 Loading	6
	4.2.2 Pressure	6
5	MATERIALS AND MIXES	7
	5.1 Binders	8
	5.2 Aggregates	8
	5.3 Mix Data	8
	5.4 Field Samples	9
	5.5 Base Lifts	9
6	BEAM TEMPERATURE PROFILES	9
7	BEAM FABRICATION	11
8	BEAM CONDITIONING	13
9	TESTING	13
10	MIX RUTTING EVALUATION	15
	10.1 Variation with Tire Loading	16
	10.2 Variation with Tire Styles at Different Temperatures	16
	10.3 W.T.M. Testing of Field and Laboratory Samples	17
	10.4 Effects of Flexible Versus Rigid Base Lifts	19
	10.5 Temperature Effect on Rutting	20
	10.6 Recommended Test Procedures	21
11	CONCLUSIONS	21
12	RECOMMENDATIONS	22

Page

REFERENCES 24

APPENDICES

A Weight Restriction by Width of Tires ..... A
B Test Method for Accelerated Rutting of Bituminous Mixtures Using a Wheel Tracking Machine ..... B

LIST OF TABLES

1 Asphalt Cement Properties 27
2 Aggregate Sources and Properties 28
3 Mix Gradations 28
4 Mix Design and Field Mix Data 29
5 Beam Top Lift Properties Before and After Testing 30
6 Effects of Initial Temperature and Number of Passes on Rutting 31
7 Mix #2 Rutting Comparison Using Different Types of Base Lifts 31

LIST OF FIGURES

1 Distribution of Bias Tire Pressures 32
2 Distribution of Radial Tire Pressures 32
3 Wheel Tracking Machine 33
4 Wheel Carriage Assembly Position: (a) Unloaded (b) Fully Loaded 34
5 Temperature Measurement Using Omega 871 Digital Thermometer with Thermocouples 35
6 Surface Temperature Measurement by Raytek Raynger II Thermometer Gun 36
7 Tire Types: (a) Treaded Pneumatic (b) Solid Urethane (c) Treadless Pneumatic 37

Page

8 Tire 'Footprints': (a) Solid Urethane (b) Treadless Pneumatic (c) Treaded Pneumatic 38
9 Change in Imprint Area with Loading for the Three Types of Tires 39
10 Relationship of Calculated Average Effective Pressure to Loading for the Different Tire Types 39
11 Asphalt Cement Viscosity Temperature Curve for Penetration Index Derivation 40
12 Temperature Profiles at Various Depths Measured at Different Time Intervals 41
13 Beam Temperature Profiles @ 30 mm Depth at Various Locations Along the Beam Width 42
14 Modified California Kneading Compactor: (a) Mould and Platform (b) Tamping Foot 43
15 Placement of a Thermocouple 44
16 Tinius Olsen Compression Machine: (a) Controls (b) Levelling Load Application 45
17 Profile and Rutting Depth Measurement 46
18 Cycle Counter and W.T.M. Beam Set-up 46
19 Change of Temperature Gradient with Number of Passes for Different Initial Sample Temperatures 47
20 Cross-Sections of H.L.-8 Mix After 8000 Passes at 60°C and 100°C 48
21 Characteristics of Badly Rutted Beams 48
22 Response of Mix #1 to Rutting Under Different Types of Tires after 10000 Passes by Constant Temperature Mode Testing 49
23 Rut Depth vs Number of Passes at Different Initial Temperatures for an H.L.-4 Mix 50
24 Rut Depth vs Number of Passes at Different Initial Temperatures for an H.L.-8 Mix 50
25 Field and Laboratory Mix Rutting after 8000 Passes at Different Initial Temperatures 51
26 Bloomington Rd. Field Sample After Testing: (a) Plan View (b) Side View 52
27 Effects of Different Types of Base Lifts on Mix #2 Rutting 53

1 INTRODUCTION

As the call for energy conservation has grown, trucking firms have cut fuel costs by using all available carrier space and by upgrading their tractor fleets with newer energy-efficient versions. Some transportation agencies have increased the permissible limits of highway carrier lengths and/or axle loads. Manufacturers have responded by building trucks with increased cargo carrying capacities.

For their part, tire manufacturers have developed the energy-efficient radial ply tire, but a substantial increase in tire pressure has accompanied its development. A 1986 Ministry of Transportation of Ontario study (1) found that an average truck radial tire pressure of 740 kPa (107 psi) prevailed as compared to 515 kPa (75 psi) for the traditional bias ply tire (Figs. 1 and 2). Some of the radial tire pressures were found to be as high as 1035 kPa (150 psi).

Highway traffic volumes are also on the increase. For example, the traffic volumes along Ontario's main freeway, Highway 401, have in some sections risen from 198600 to 279400 vehicles daily in the past ten years according to the Ministry's records (2).

These developments have brought one form of pavement distress to the forefront, viz., rutting along the wheel tracks. The pavement channelling, characteristic of rutting, makes vehicle steering more difficult. Inability of water to escape the tracking channels can also result in vehicle hydroplaning. Rutting provides areas for winter snow and ice to collect to become a hazard for the motoring public. In view of this, rutting is considered one of the most important modes of flexible pavement failure (3). Remedial action in terms of pavement rehabilitation or reconstruction is costly. As such, it is understandable that much research has been undertaken to examine, predict and/or correct possible causes.

2 BACKGROUND

Rutting occurs along traffic wheel tracks and is the summation of permanent deformation of all layers in the pavement. Initially, mix densification occurs due to traffic, causing pavement deformation with volume change. Further traffic loading causes the pavement to permanently deform at constant volume until the severity of this second stage requires pavement rehabilitation. Some authors suggest that 10 to 12 mm (0.4 to 0.5 in) be the functional failure limit (4,5,6) for this type of distress.

A theoretical approach for the analysis of rutting has been to consider pavements as multilayered elastic systems. Each finite layer is assumed to be homogeneous, isotropic and linear in material properties (7). The layers are assumed to be infinite in the lateral directions with full friction between layers. Nonlinear materials can be described as linear if the stress state is low enough. The engineering properties of the pavement are characterized for each layer by the elastic modulus, E, and Poisson's ratio, μ.

Characterization of permanent strain in the asphalt layers of the theoretical system can be determined through triaxial indirect tension repeated load testing. Multiple regression can also be used to relate permanent deformation potential to stress and material stiffness using the material characterizations mentioned above. This method has been used by both Kirwan (8) and Haas (9). However, the problem with the 'layer strain' model has been the inability of results to predict the ridge that forms adjacent to the rut.

Viscoelastic theory can be used to supplement the 'layer strain' theory. Through the use of Maxwell or Kelvin type spring-dashpot systems (7), the viscous or time-dependent properties of the pavement material can be incorporated to better predict permanent deformation. This 'separative approach' of Thrower (10) uses strains from the multilayer elastic analysis to initiate the calculations for the viscoelastic analysis. The advantage of this model is that the pavement rise adjacent to the wheel

track rutting can be successfully modelled. However, the theory analyzes the pavement materials as linear which they are not.

Permanent strain material characterization can be utilized to develop computer structural models of pavements. Rauhut (11) uses VESYS, a viscoelastic based program utilizing repetitive-loading compression tests to obtain permanent strain properties. He defines two rutting parameters ALPHA (α) and GNU (μ) derived on the basis that the logarithmic relationship between permanent strain and number of loadings is linear over a range of load repetitions. By increasing ALPHA or decreasing GNU, the amount of predicted rutting is reduced.

But it is only by physical comparative evaluation that these theoretical models can be verified and to that end, many traffic simulating wheel tracking machines have been developed. Examples of these are Shell Research's circular tracking model and the full scale linear tracking Danish Road-Testing Machine (12) which can control environmental factors including groundwater levels. Another such machine is the Australian designed "Accelerated Loading Facility (ALF)". The ALF machine (13), unlike the Danish R.T.M., loads pavements unidirectionally and is therefore more realistic. On a smaller scale many laboratory tracking machines have been built to evaluate rutting. One of these is the Ontario Ministry's Wheel Tracking Machine (W.T.M.) fabricated by Gulf Canada Limited.

3 PURPOSE AND SCOPE

This study sets out to determine the capability and sensitivity of the Wheel Tracking Machine to evaluate rutting of asphalt mixes in a laboratory. This involves a complete review of machine variables as well as development of proper test procedures. The study will:

a) evaluate the effects of three possible tire styles for testing with the W.T.M. A 'footprinting' technique will be used to compare inflation pressures to calculated tire sample surface contact pressures.

b) develop W.T.M. standard procedures to examine rutting at constant temperatures at simulated summer pavement conditions. 'Constant temperature mode' will hereafter refer to the procedure of sample fabrication, conditioning and testing under these conditions.

c) develop W.T.M. procedures to examine the rutting effect of traffic on compacted asphalt mixes during cooling immediately after construction. 'Decreasing temperature mode' will hereafter refer to sample fabrication, conditioning and testing under these conditions.

d) determine suitable arrangements for heating, controlling and recording beam temperatures for the constant temperature mode and decreasing temperature mode procedures by measuring the beam matrix and surface temperatures.

e) compare the effects of using flexible versus rigid base lifts underneath the surface lifts.

f) examine the degree of rutting produced, and the variables involved, by the proposed W.T.M. procedures using two laboratory mix designs and four field samples selected from rutted pavements.

4 WHEEL TRACKING MACHINE

The equipment involved (Fig. 3) in this study, was purchased from Petro-Canada Inc., formerly Gulf Canada Ltd. It consists of three parts:

a) constant temperature reservoir
b) wheel carriage assembly (Fig. 4)
c) motor and drive linkage assembly

All of these parts work in unison to produce a back and forth movement of the tire along the length of the beam sample. They are described in more detail as follows.

4.1 Machine Components

The reservoir is sufficiently large at 700 mm length x 735 mm width x 230 mm depth ($27\frac{1}{2}$ x 29 x 9 in) to allow for the concurrent testing of two samples. The samples, each 381 mm length x 140 mm width x 76 mm thickness (15 x $5\frac{1}{2}$ x 3 in), are housed in 13 mm ($\frac{1}{2}$ in) thick steel moulds. These are set into stainless steel holding containers with dimensions of 580 mm length x 250 mm width x 150 mm depth ($22\frac{3}{4}$ x $9\frac{3}{4}$ x 6 in). The containers are then fit into a submerged steel frame inside the reservoir.

Constant heat is supplied to the water by three heating coils and a fluid circulating pump. All bath and internal beam temperatures are monitored by chromel-alumel thermocouples connected to an Omega 871 Digital thermometer (Fig. 5) while beam surface temperatures are obtained using a Raytek Raynger II non-contact infrared sensing thermometer gun (Fig. 6). Heat to the specimen surface is supplied by infrared lamps, which can be rheostat-adjusted to produce various beam constant surface temperatures.

The wheel carriage assembly contains a tire with its rim mounted on ball bearings to minimize friction. The tire is mounted under the assembly and its axle is secured to the carriage. Above the carriage is an assortment of pegs on which varying loads can be placed. The assembly is secured to a crossframe by a hinge to allow free vertical movement of the complete unit with little friction.

The motor of the W.T.M. is connected to two flywheels, one on either side of the machine through which the driving force is transmitted. Two connecting shafts eccentrically attached to the flywheels impart the driving force to a moving crossframe. The amount of backward and forward movement determines the length of the path, in this case 254 mm (10 in). It can be altered by changing the eccentric positioning of the connecting shafts on the flywheels. The crossframe moves back and forth at a rate of 32 cycles or 64 passes per minute along two large

horizontally mounted guide rods and connects the power train to the wheel assembly.

4.2 Tires

In order to determine a suitable tire for the test and because full scale truck tires could not be used due to limitations in the size of machine and specimens, three narrower width tires were tested (Fig. 7):

a) a treadless 43 mm (1.70 in) wide and 197 mm (7.76 in) diameter solid urethane faced tire.

b) a pneumatic treadless tire with a 50 mm (1.96 in) surface contact width and an outer diameter of 270 mm (10.62 in). The tire is designated by the manufacturer, Cheng Shin Company of Taiwan, as a 3.40/3.00 - 5 tube type with a 4 ply rating.

c) a treaded pneumatic tire manufactured by the Goodyear Tire and Rubber Company, specified as a 4.10 - 4 industrial tire with a 4 ply rating and a Shore durometer hardness value of 70. The tire has an outer diameter of 267 mm (10.52 in) and a tread width of 70 mm (2.76 in).

4.2.1 *Loading*

The W.T.M. weights can be assembled to give various tire loadings up to 65.5 kg (144.4 lb). Based on the width to weight restrictions set by the Compliance Branch of the Ministry (14), loads up to 387 kg (853.2 lb), 450 kg (992.0 lb), and 630 kg (1 389.0 lb) could be levied on the solid urethane, the 'slick' and the treaded tire respectively (Appendix A). This means that the full loading of 64.6 kg (142.4 lb) to 65.5 kg (144.4 lb) available to the W.T.M. (depending on the tire used) would constitute approximately 10 to 17% of the legal maximum load limit allowed on Ontario roads.

4.2.2 *Pressure*

For safety reasons a maximum tire pressure of 550 kPa (80 psi) was selected for the tires. Based on a survey by the Research and Development Branch on truck tire pressures in the province (1), this would represent

not only the average bias tire pressure but also the lower radial truck tire pressures.

To determine the equivalent pressure for the solid urethane tire, a 'footprinting' technique was used. Planimeter area measurements from inked tracings of tire prints (Fig. 8), along with loadings, were utilized. By this method, the apparent average contact pressure of the urethane tire was determined. Similar information was also gathered for the pneumatic tires.

a) Urethane Tire

Due to its solid state the shape of the urethane tire 'footprint' altered insignificantly under loading. Under the maximum W.T.M. load of 64.6 kg (142.4 lb), the calculations from planimeter readings gave an equivalent average contact pressure of 1 580 kPa (229 psi). The ratio of varying tire loads to tire 'footprint' areas (Fig. 9) indicated a load of 16.4 kg (36.2 lb) was required to give a 550 kPa (80 psi) average contact pressure. This was verified by making up a 16.4 kg (36.2 lb) mass and assessing the surface contact area.

b) Pneumatic Tires

From the measurements of contact area under loading shown in Figure 10, the two types of pneumatic tires exhibited the same apparent average contact pressure. Regardless of the loading, the calculated average contact pressure stayed at 510 kPa (74 psi), approximately 92% of internal tire pressure.

As a result, a loading of 65.5 kg (144.4 lb) and 550 kPa (80 psi) pressure were used for the pneumatic tires and a 16.4 kg (36.2 lb) load was used for the urethane tire to produce the equivalent 550 kPa (80 psi) pressure.

5 MATERIALS AND MIXES

The selection of mixes for making the laboratory samples was based upon their different Marshall stability values. For field samples, the selection was based on the rutting as recorded during site investigations.

5.1 Binders

The laboratory manufactured mixes used an 85/100 penetration grade asphalt cement which met the Ministry's specifications (15). Its physical properties shown in Table 1 include a penetration of 90 at 25°C and an absolute viscosity of 152 Pa.s at 60°C combining to give a penetration index of -0.7 (Fig. 11), a value common for paving asphalts.

A 150/200 penetration grade A.C. was used with the R.A.P. and virgin aggregates in a recycled hot mix from which the recovered penetration was determined to be 47 and the recovered kinematic viscosity, 492 mm^2/s (492 centistokes).

5.2 Aggregates

For the laboratory manufactured mixes, two coarse aggregates were obtained from the Durham and the Vicdom pits as were the two fine aggregates. Analysis indicated a large difference in petrographic number as well as a sizeable change in the percent crushed contents of the mainly carbonitic coarse aggregates (Table 2).

The recycled hot mix used in part of the study came from Contract #83-43. It consisted of 25% R.A.P. traprock and local fine aggregates. The 75% virgin portion of the mix used Dofasco steel slag for the coarse and fine aggregates (Table 2).

5.3 Mix Data

All mix designs were carried out according to the Ministry's L.S. Manual (16) and Specifications (15). Gradations for these are shown in Table 3 and the design data is listed in Table 4. Combining the Durham coarse and fine aggregates produced an H.L.-4 mix with 55% by mass passing the 4.75 mm (#4) sieve and a Marshall stability of 13600 N (3060 lbf). The other mix, an H.L.-8 consisting of Vicdom coarse aggregate with Miller fine aggregate, gave a stability of only 9100 N (2040 lbf) at 55% by mass passing the 4.75 mm (#4) sieve.

Mix #1 (H.L.-4) was slightly off specification as the V.M.A. value of 13.8% did not meet the required specification value of 14.5% minimum. However, modification of this mix was not contemplated as there was only limited material available for the testing.

Mix #3 (H.L.-1 R.H.M.), used in evaluating the effects of flexible versus rigid bases on rutting, contained 2.7% voids with an 11.8% V.M.A. At 55% by mass passing the 4.75 mm (#4) sieve, the Marshall mix stability (Table 4) was a high value of 23000 N (5180 lbf).

5.4 Field Samples

Samples were sawn directly from sections of the highways investigated previously for rutting (17). They included the three sections from Highway 401 in the Port Hope District and a section from Bloomington Road. Specimens were cut from these sections to fit the dimensions of the W.T.M.'s moulds. The recompacted mix data for these sections can be found in Table 4.

5.5 Base Lifts

The effects of rigid bases on total measured rutting was determined using 38 mm ($1\frac{1}{2}$ in) thick plywood. For comparison, two other flexible base lifts were tried. The first was the H.L.-4 Durham C.A. and Durham F.A. mix while the second was the high stability H.L.-1 R.H.M. steel slag and traprock mix. As little variation in rutting was expected using these three types of bases, the low stability H.L.-8 mix was used as the top lift to accentuate any differences.

6 BEAM TEMPERATURE PROFILES

Many factors affected the variability of the internal and surface temperature of a beam. While losses to the atmosphere and bath water were taking place, heat content was maintained by both the infrared lamps (simulating solar radiation) and the heated bath water. As the shadow

cast by the tire assembly affected the surface temperature of the sample, the infrared lamps were adjusted to an angle that minimized the heat flow interruption caused by the shadow.

To determine the appropriate starting time for the rutting test, the internal temperature measurement of the beam samples was required. This information was obtained by recording the readings from a thermocouple placed in the beam during its manufacture (Figs. 5 and 15).

During the initial beam compaction trials, temperature data gathered by a thermocouple placed approximately 6 mm ($\frac{1}{4}$ in) above the bottom lift indicated that temperatures had dropped to approximately 70°C by the end of beam manufacture. As initial beam temperatures ranging from 60°C to 100°C were required for the decreasing temperature mode method, reheating of the samples to desired temperatures was required in some cases. All of the above considerations necessitated profiles be established for both the internal and external beam temperatures.

To determine the temperature gradients, temperature data was collected from two beams using actual test conditions. In the first beam, five equidistant probes were positioned in drilled holes along the centreline of the wheel path at depths ranging from 10 to 50 mm (0.40 to 1.95 in) successively. After cementing the probes in place with asphalt cement, the beam temperature was raised to 110°C in an oven. Upon removal from the oven, the beam was positioned in the W.T.M. in approximately 13 mm ($\frac{1}{2}$ in) of water at 60°C and the infrared lamps were adjusted to produce 60°C at the specimen's surface. This temperature approximates the maximum reached by some Ontario pavement surfaces in mid-summer. Temperature readings from the probes were taken immediately and as often as possible until the internal beam temperature dropped to 60°C. A period of approximately four hours was required.

A temperature profile of the cooling beam is shown in Figure 12. Lines at different time intervals indicate that the surface cools rapidly at the beginning. However the infrared lamps tend to slow down the rate of

cooling until an equilibrium surface temperature of 60°C is reached. At the same time, the bath water tends to cool down the bottom surface much more rapidly but stabilizes it at approximately 60°C. The slowest rate of cooling occurs at a depth of 30 mm (1.20 in); hence, a location just above the interface of the two lifts at a depth of 30 to 34 mm (1.20 to 1.35 in) was chosen as optimal for thermocouple placement. This position, as well as being a good indicator of the lagging temperature change inside the beam sample, also minimized the variability of heat losses during specimen manufacture because of the ease of thermocouple placement.

In the second beam, the effectiveness of the infrared lamps was determined by placing five thermocouple probes spaced 25 mm (1.00 in) apart in the centre area of the beam perpendicular to the longitudinal axis at a depth of 30 mm (1.20 in). Once again the beam was heated in an oven to 110°C, then placed in the W.T.M. and submersed in approximately 13 mm ($\frac{1}{2}$ in) of water at 60°C. At all temperatures the infrared lamps had a moderating effect on specimen heat loss (Fig. 13), more so on the side of the beam closest to the infrared lamps. Other than at the very beginning of the cooling, the maximum temperature occurs at the centreline of the beam with a reduction on either side of up to 4 C°. Insulating the sides of the mould reduced that to 2 C°. After more than 240 minutes, all probes registered an equilibrium temperature of 60°C.

Only a slight temperature profile gradient is seen across the width of the beam once the W.T.M. is started. A difference of 2 C° is produced by the wheel carriage shadow from the 25 mm to 115 mm (1.00 in to 4.55 in) markings. This represents the beam transverse distance covered by the wheel.

7 BEAM FABRICATION

All beams were produced in two lifts, each approximately 38 mm ($1\frac{1}{2}$ in) in thickness, by a modified California type kneading compactor with a 133 x 76 mm ($5\frac{1}{4}$ x 3 in) rectangular tamping foot (Fig. 14). Prior to mixing, a

batch of 4500 g (9.920 lb) aggregate was heated to 170°C and the asphalt cement temperature was maintained at a level corresponding to a viscosity of 170 ± 20 mm^2/s (170 ± 20 centistokes). After mixing, the material was covered with foil and returned to the oven until the temperature again rose to 170°C, usually an hour later. Then some of the mix was placed in the beam mould to form a layer approximately 6 mm ($\frac{1}{4}$ in) thick. A probe wire was placed 70 mm ($2\frac{3}{4}$ in) from the nearest side (Fig. 15). This was overlaid by the remainder of the mix. The rodding action of a wide scraper perpendicular to the mould length ensured the even spread of the mix. A compactive effort of 40 tamps at a foot pressure of 425 kPa (62 psi), followed by 40 tamps at 505 kPa (73 psi), 40 tamps at 895 kPa (130 psi) and 60 tamps at 1345 kPa (195 psi), was respectively applied.

The compacted lift was immediately transferred to a Tinius Olsen compression machine (Fig. 16) where a rate of load application of 6 mm (0.25 in) per minute was applied until a finishing levelling load pressure of 2760 kPa (400 psi) was reached. The application of this maximum pressure for a period of one minute completed the manufacture of the lift.

The above procedure produced a target compaction of 96 ± 1% for the Durham and Durham mix. For experimental consistency, the same method was followed in the compaction of all manufactured lifts, both for decreasing and constant temperature modes and for surface and base lifts. The top lifts were made only after the bottom lifts had set for 24 hours.

Once a beam was manufactured, either with two separate lifts or with a single lift on top of 38 mm ($1\frac{1}{2}$ in) of plywood, profiles were taken transversely (across the beam width) at three selected points: the middle and end points of the W.T.M. wheel travel. A 152 mm (6 in) wide carpentry profilometer (Fig. 17) was used to obtain the initial surface levels. After this, the beam was ready for temperature conditioning.

8 BEAM CONDITIONING

Even though the initial compaction temperature was high, the maximum temperature upon completion was around 70°C due to the length of time required for kneading and levelling. This was lower than some of the initial temperatures required for the decreasing temperature mode testing and also lower than the normal pavement finishing temperature of 80°C to 100°C in the field. To bring specimens up to the required initial temperatures, the beams were covered with a steel plate and reheated in an oven. The heating time varied from four to thirty minutes depending upon the internal beam temperatures.

Upon the internal reading reaching the required initial temperature, the covered beam was taken out of the oven and completely wrapped in insulation to control heat dissipation. Cellulose fibre, fibreglass bats or styrofoam are appropriate. When readings had stabilized within 2°C and the interface temperature between the lifts indicated a deviation of only 1°C from the required test temperature, most of the surrounding insulation was removed leaving only some styrofoam insulation taped to the sides of the mould to minimize lateral heat losses. The beam assembly, surrounded by the styrofoam insulation, was positioned in the W.T.M. in 13 mm ($\frac{1}{2}$ in) of water.

The procedure differed at this point in the case of the constant temperature mode in that all insulation was removed and in lieu of insulation, the water level in the W.T.M. was increased to within 13 mm ($\frac{1}{2}$ in) of the mould top. The mould and beam assembly in position in the wheel tracking apparatus was now ready for testing.

9 TESTING

As this is an evaluation of the W.T.M., an extended number of passes were used, 10 000 for constant temperature mode and 8 000 for decreasing temperature mode. The longer beam conditioning time needed for the decreasing temperature mode required a reduction in the number of passes

to 8000 to facilitate the daily work schedule. Subsequent results showed that 4000 passes are sufficient for both modes of testing.

Testing was performed on beams of the H.L.-4 mix to assess the subtle rutting variations produced by the different tire styles. Constant temperature was used as this involved fewer stages in sample preparation and consequently, less error.

For the testing of the field samples by treaded pneumatic tire, the conditioning of the beams was accomplished by overnight heating in an air bath at a temperature of 60°C. The specimens were then run in the W.T.M. at a constant temperature of 60°C.

Comparison of the H.L.-4 and H.L.-8 mix types as well as the assessment of the different base lifts on rutting was carried out by the decreasing temperature mode of testing using the treaded pneumatic tire. For an initial temperature of 60°C, this mode provided a constant temperature comparison of the above samples.

With the sample in place, the infrared lamps turned on, and a load of 64.6 kg (142.4 lb) to 65.5 kg (144.4 lb) on the pneumatic tires or 16.4 kg (36.2 lb) on the solid urethane tire, the W.T.M. was started. Testing at constant temperature mode carried on for a total of 5000 cycles or 10 000 tire passes. The number of passes was recorded by an automatic counter (Fig. 18) at one end of the W.T.M. wheel travel. Testing lasted 156 minutes at the machine operating frequency of 32 cycles or 64 passes per minute.

Temperatures from the bath and the sample container were continuously monitored by thermocouples in the water. Base and interface probe temperatures were likewise monitored. Beam temperature patterns with time during the decreasing temperature mode testing are displayed in Figure 19.

Specimen transverse profiles and surface temperatures were assessed periodically during the testing using the profilometers and the thermogun

respectively. This occurred at the 500, 1000, 2000 and 4000 pass marks when the W.T.M. was stopped for 25 to 30 seconds. The profiles were taken at exactly the same positions for all measurements, at the middle and end points of wheel travel. Final transverse profiles were taken at the completion of testing. A longitudinal profile of the rutting was made from these results and the average rutting along the 254 mm (10 in) of wheel travel was calculated.

Upon cooling overnight, the beams were extruded and examined. To compare the effects of tire action on mix compaction, the beams were cut into portions and bulk relative densities were taken both on and off the wheel track areas. Relevant beam data before and after testing are shown in Table 5.

10 MIX RUTTING EVALUATION

The signs of rutting appeared as early as 50 passes after the start of tire travel over the beam surface. As the depressions in the wheel track became more pronounced, the height of the mix adjacent to the rut increased and random hairline cracking appeared alongside the track. On some of the deepest rutted beams, the tracked area appeared flushed as asphalt cement was pumped to the surface by the tire action.

The amount of rutting, measured from the wheel track valley to the initial profile line, varied directly with the initial temperature as can be seen from Figure 20 for the H.L.-8 mix. In Figure 21 the increase in height adjacent to the wheel track is visible along with its associated cracking. Changes in the properties of mixes #1 and #2 as a result of the testing are shown in Table 5.

Variation in the rate of rutting occurred over the course of a test run. There was a rapid rate of deformation in the first 500 to 1000 passes. The rate then diminished to a constant low rate of rutting over the final 2000 to 4000 passes. The high initial rate is suspected to be a mix densification stage caused by particle reorientation and void reduction under the tire kneading action.

10.1 Variation With Tire Loading

As discussed earlier, 'footprinting' determinations in Section 4.2.2 indicated that at a loading of 64.6 kg (142.4 lb) the solid urethane tire produced a surface contact pressure of 1 580 kPa (229 psi) whereas the contact pressure of the pneumatic tires was proximate to the inflation pressure of 550 kPa (80 psi). The results (Fig. 22) show that because of the higher contact pressure, the urethane tire produced fivefold the rut depth as that of the pneumatic tires, i.e., 14.6 mm (0.574 in) versus an average of 3 mm (0.12 in) at a temperature of approximately 63°C.

Under the same loading and in order to produce a similar level of rut depth as the urethane tire, substantial changes were required to the 63°C temperature and 550 kPa (80 psi) pressure of the pneumatic tires. For example, at temperatures of 77°C and 73°C and at a pressure of 690 kPa (100 psi), 16.2 mm (0.638 in) and 10.0 mm (0.394 in) of rutting were produced by the treadless and treaded pneumatic tires respectively.

When comparing the effects of the three types of tires on rutting at a constant pressure of 550 kPa (80 psi), the loading on the urethane tire had to be reduced to 16.4 kg (36.2 lb) to obtain a contact pressure of 550 kPa (80 psi). At the temperature of 63°C, a rut depth of 1.6 mm (0.062 in) was obtained using the urethane tire (Fig. 22) versus a rut depth of about 3 mm (0.12 in) for the pneumatic tires. Since the pneumatic tires more closely simulate vehicular tires used on the road, maintain a constant contact pressure under varying loads, and can produce higher rut depths (more sensitive) than the urethane tire, the experimental data supports the use of pneumatic tires for the rutting test under investigation.

10.2 Variation with Tire Styles at Different Temperatures

Rutting results that compared tire style effects at various constant temperatures showed a marked spread. For temperatures ranging from 49.5 to 73.5°C, a spread of only 24 C°, ruts (Fig. 22) of 0.7 to 7.5 mm (0.028 to 0.296 in) after 10 000 passes or 5 000 cycles at 550 kPa (80 psi) were obtained; in all cases the amount of rutting increased with

higher bath temperatures. At 55°C, an average rut of 1.6 mm (0.062 in) with a range of 1.5 mm (0.060 in) was obtained from the tests using the three tires. At 63°C, the average value rose to 2.5 mm (0.098 in) while the range increased to 2.2 mm (0.086 in).

Of the three types, the urethane tire produced the least rutting and the poorest repeatability. Therefore its use at low levels of deformation or for differentiating the rutting potential of similar mixes would require a greater testing time interval. As well, compensation would have to be made for its poor precision through greater test sample replication.

The treadless pneumatic tire, incorporating the treadless feature of the solid urethane as well as the pneumatic state of the treaded tire, produced rutting depths intermediate to the others at all temperatures tested.

As well as physically resembling vehicular tires more than do the treadless pneumatic and the solid urethane tires, the treaded pneumatic tire is more discriminating because it produced greater rutting at all test temperatures. Therefore, it is better with respect to differentiating the rutting potential of mixes, particularly with low or similar levels of rutting. This comparison indicates the importance that tire style has on rutting.

10.3 W.T.M. Testing of Field and Laboratory Samples

Results in Table 6 demonstrate the success of the W.T.M. with the treaded pneumatic tire in rutting both of the designed mixes. With a deformation ranging from 1.8 to 6.9 mm (0.070 to 0.272 in), the high stability H.L.-4 mix averaged approximately 38% of the rutting produced by the low stability H.L.-8 mix.

A measurable amount of rutting, 0.8 mm (0.032 in) was detected in the H.L.-4 after only 500 passes using an initial temperature of 60°C. With both increasing number of passes and increasing initial temperatures, a general upward trend in rutting was noted. The individual mix rutting

patterns with regard to the number of passes and initial beam temperatures are shown in Figures 23 and 24.

The relative rutting potential of the two laboratory mixes was easily observed at 60°C, the lowest baseline temperature used. Thus the W.T.M. appears sensitive to even the minor rutting levels produced by the laboratory mixes at the temperatures in question.

As shown in Figure 25, the rutting produced by the W.T.M. on some of the field samples was extensive. After only 500 passes at the constant testing temperature of 60°C, the Bloomington Road specimen (Fig. 26) exhibited 34.7 mm (1.366 in) of rutting, an increase of 570% over the 5.2 mm (0.205 in) produced by the H.L.-8 laboratory mix at the same temperature. The sample from Highway 401, Port Hope, showed almost 110% more rutting than the H.L.-8 mix after 8000 passes. Trench 'B' produced as much rutting, 5.2 mm (0.205 in) as the H.L.-8 mix at 60°C. While trench 'A' exhibited moderate rutting of 3.6 mm (0.142 in), this was still 100% more than that produced by the H.L.-4 mix. Hence the amounts of rutting produced by the W.T.M. on known rutting mixes surpasses in most instances those produced on laboratory produced mixes. Known rutting mixes, therefore, can be differentiated by the action of the W.T.M.

The only drawback to the testing of field specimens is that these beams, not being manufactured in the W.T.M. moulds as were the laboratory specimens, may allow higher side mounding of mix from under the tire because of lower wall friction. This would produce more rutting than would be observed if the field mix beams were laboratory manufactured.

Through its ability to induce rutting quickly and in some cases substantially, the W.T.M. has demonstrated the capability of differentiating between the rutting of various mixes. The greater degree of deformation produced by the W.T.M. on known rutting field samples holds promise of this machine's potential in detecting mixes which are unsuitable for our highway pavements.

10.4 Effects of Flexible Versus Rigid Base Lifts

This portion of the study used the high Marshall stability H.L.-4 (mix #1) and a very high stability recycled H.L.-1 mix (Table 4) from Contract #83-43 as alternative flexible base lifts. Choosing of the H.L.-1 R.H.M. was based on field experience where this mix had a stability of 23000 N (5170 lbf) and showed little rutting as a surface course.

To compare the selected mixes for rutting resistance, beams were made of each mix and tested by the W.T.M. at constant temperature using the solid urethane tire at a calculated tire pressure of 1580 kPa (229 psi). The H.L.-4 beam rutted 14.6 mm (0.574 in) at 64°C after 10000 passes (Fig. 25) while the H.L.-1 R.H.M. beam rutted only 5.6 mm (0.220 in) or 40% as much at 59°C after twice as many passes. Hence, much greater rutting resistance was exhibited by the H.L.-1 beam than by the H.L.-4 beam even though conditions were more severe.

When the two bases were used as the bottom lifts for the H.L.-8, the H.L.-1 R.H.M. mix was less impressive in reducing rutting as shown in Table 7 or Figure 27. An average reduction of approximately 1 mm (0.04 in) of rutting resulted after 8000 passes using the decreasing temperature mode at different initial temperatures. This is not due to a deficiency on the part of the H.L.-1 R.H.M. but to the fact that the stress is lower at the base lift level than at the surface. Because of this, the H.L.-4 base lift rutting is greatly reduced and hence the total beam rutting is also reduced. Considering that the total rutting ranged as high as 17.4 mm (0.686 in), the findings indicate the effect of using the H.L.-4 mix rather than a very high stability mix as a base lift throughout the study, is minimal.

Plywood, used as a 38 mm ($1\frac{1}{2}$ in) thick rigid base for the H.L.-8, also appeared to reduce the amount of total rutting. For initial temperatures of 75 and 100°C, the reduction was approximately from 2 to 5 mm (0.08 to 0.20 in) respectively or 25%. For the other temperatures however, the difference in results was 1 mm (0.04 in) or less. The inconsistency may

be due to slight delamination and warping of the plywood in contact with the hot bath water over a period of time. Newly cut plywood was used for testing at 75 and 100°C, but was reused for testing at 60, 70 and 82.5°C. Under the action of the W.T.M. wheel loading, the warped weakened plywood might cause mix flexing, decompaction and excess rutting. Another reason for the inconsistency might be the loss in adhesion in some of the cases between the top lift and the partially dry wooden surface, creating higher tensile strains at the bottom of the top lift and more rutting. This critical increase in strain due to delamination between surface and binder has been documented by Shahin et al (18).

The use of rigid base lifts appears to reduce the rutting of the beam samples. The replacement of bases by higher stability mixes reduces beam rutting as well. This indicates that the rutting process involves all layers of a pavement. Therefore, beams manufactured for W.T.M. studies should realistically model the pavements to be examined, whether they be total flexible pavements or whether they are flexible overlays on rigid bases such as concrete. However, for comparative testing, an H.L.-4 mix using Durham coarse and fine aggregates is considered suitable.

10.5 Temperature Effect on Rutting

The ability of the W.T.M. to produce high rutting levels allows the use of shorter testing periods to define the rutting potential of the beams in question. In an evaluation of mixes with extremely low levels of rutting, the use of higher temperatures either by the use of the constant temperature or decreasing temperature modes of testing results in more measurable rutting being produced even though higher temperatures may not simulate the higher summer temperatures. As shown in Table 6 rutting increases up to 600%, if 100°C rather than 60°C is used as the initial temperature for the testing of the H.L.-4 mix by decreasing temperature mode. Similar changes can be seen for the H.L.-8 mix. This increase in rutting with temperature rise is important as errors resulting from rutting measurement or from beam homogeneity are factors that reduce the method's precision. Higher temperatures also provide the sensitivity to study the effects of varying mix design parameters such as

H.L. types, % pass 4.75 mm (#4) sieve, % A.C., % voids, mix stability, etc. where minor rutting deviations may result from a change in the level of a parameter.

However, one of the dangers of the decreasing temperature mode method is the required beam reheating. Asphalt hardening occurs which raises the mix stability and stiffness values thereby lowering the amount of W.T.M. induced rutting.

10.6 Recommended Test Procedures

The two methods used to determine the W.T.M.'s ability to evaluate varying levels of rutting proved to be satisfactory. Of the two methods, the constant temperature mode is the easiest in terms of beam conditioning. For studies where temperatures of less than 70°C are involved, the beam reheating process after compaction can be discarded to reduce the preparation interval and to prevent A.C. hardening. A write-up of the constant temperature mode using only 4 000 passes for standard testing of mix design rutting evaluation at 60°C is described in Appendix B.

The decreasing temperature mode provides a method for studying rutting effects caused by traffic onset after the finish of construction, while pavement temperatures are higher than ambient. This method, while quite demanding in terms of time and temperature care, can model the pavement temperature gradients in effect. Because of higher initial testing temperatures, the level of rutting produced by this method is greater than by the constant temperature mode. This is an important consideration if slight variations in materials or mix design are being compared. The decreasing temperature mode method is described in Appendix B.

11 CONCLUSIONS

This study has shown that the W.T.M. is an excellent tool in examining the problem of pavement rutting. Listed below are the findings of the study.

a) The W.T.M. can be successfully used as a laboratory tool for the accelerated testing of the rutting properties of both laboratory prepared and field pavement samples.

b) The W.T.M. has the ability to examine rutting under a variety of test conditions.

c) Two testing procedures were developed for the W.T.M. One studies the potentials of mix designs for rutting under constant temperature conditions. The other method examines traffic induced rutting during the cool-down period immediately after hot mix construction. Standard procedures have been established for the two methods (Appendix B).

d) A treaded pneumatic tire has been selected as a standard for the W.T.M. test. More realistic rutting has been detected for mixes tested under the treaded pneumatic tire than under the treadless pneumatic or the solid urethane tire.

e) Since rutting is the summation of deformation in each layer of the beam, using a higher stability mix in the base lift also decreased the total rutting of the flexible pavement under the same conditions. Substituting a rigid base lift for a flexible one further reduced the amount of rutting. A base mix using Durham coarse and fine aggregates has been established as a standard for use in future testing.

f) The degree of rutting was found to be a function of temperature, tire pressure and loading. A rise in any of these parameters increased the amount of rutting.

12 RECOMMENDATIONS

a) With the aim that the W.T.M. is to be used for predicting the rutting potential of asphalt mixes, data based on laboratory mix designs, W.T.M. results, traffic and service conditions of highways, should be compiled to establish acceptance criteria.

b) From tests of the same mixes, other material properties obtained by resilient modulus, Gyratory Testing Machine and creep compliance testing, should be assembled along with the W.T.M. rutting data. This should aid in predicting the rutting potential of mixes during design.

c) Ideally, the potential of rutting evaluation should accurately model the pavement condition under consideration. For example, mixes placed on rigid surfaces such as portland concrete should be tested as such in the W.T.M. Hot mix placed in the field over a flexible lift should likewise be modelled in the making of beams for W.T.M. study.

d) A study in greater detail of the effect of mix variables on rutting, such as aggregate shapes, percent crushed content, % A.C., % pass #4 sieve, % compaction, and stability, should be undertaken.

e) Automation of the testing should be undertaken to improve the efficiency of testing as well as the accuracy of results.

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Table 1 ASPHALT CEMENT PROPERTIES

	H.L.-4 and H.L.-8	H.L.-1 R.H.M.
Pen. @ 4°C, 100 g, 5 s	9	---
Pen. @ 4°C, 200 g, 60 s	31	---
Pen. @ 10°C, 100 g, 5 s	18	---
Pen. @ 25°C, 100 g, 5 s	90	---
Softening Point(R&B), °C	46.8	---
Abs. Visc. @ 60 °C, Pa.s	152	---
Kin. Visc. @ 121.1°C, mm^2/s	727	---
Kin. Visc. @ 135°C, mm^2/s	338	---
Kin. Visc. @ 148.9°C, mm^2/s	189	---
Relative Density @ 15.6°C	1.026	---
C.O.C. Flash, °C	308	---
% Solubility in Tri.	99.96	---
Duct. @ 4°C, cm	15+	---
% Loss by Thin Film Oven	0.11	---
AFTER THIN FILM OVEN TEST:		
Pen. @ 25°C, 100 g, 5 s	55	---
% Original Penetration	61	---
Duct. @ 25°C, cm	100+	---
AFTER ABSON RECOVERY:		
Pen. @ 25°C, 100 g, 5 s	42	47
Abs. Visc. @ 60°C, Pa.s	1298	---
Kin. Visc. @ 135°C, mm^2/s	737	492

Table 2 AGGREGATE SOURCES AND PROPERTIES

Mix #	H.L. Type	Coarse Aggregate					Fine Aggregate		
		Type	Source	Mineral Aggregate Inventory Number	% Crushed	P.N.	Type	Source	Mineral Aggregate Inventory Number
1	4	95% carbonate 5% granite	Durham	D6-5	80+	115	carbonate	Durham	D6-5
2	8	90% carbonates,sandstones 10% granite gneiss	Vicdom	N2-124	67	139	carbonate,granitic material	Miller	N2-77
3	H.L.-1 R.H.M. (25/75)	traprock	R.A.P. - previous H.L.-1	---	100	---	local sand	R.A.P. - previous H.L.-1	---
		steel slag	Dofasco	---	100	---	steel slag	Dofasco	---

Table 3 MIX GRADATIONS

Mix#	H.L. Type	Sieve Size											
		19.0 mm	16.0 mm	13.2 mm	9.5 mm	6.7 mm	4.75 mm	2.36 mm	1.18 mm	600 um.	300 um.	150 um.	75 um.
1	H.L.-4	-----	2	11	31	41	45	55	64	74	87	94	96.5
2	H.L.-8	2	13	23	37	-----	45	49	53	61	79	93	97.3
3	H.L.-1 R.H.M.	-----	-----	-----	10	27	45	64	75	83	90	94	95.2

Table 4 MIX DESIGN AND FIELD MIX DATA

Mix #	H.L. Type	% A.C.	% Retained 4.75 Sieve	B.R.D.	M.R.D.	Stability (N)	Flow (0.25 mm)	%Voids (Surface Dry)	% V.M.A.
MIX DESIGN DATA:									
1	4	5.3	45	2.412	2.547	13600	10.4	4.0	13.8
2	8	5.5	45	2.358	2.466	9100	8.0	3.0	16.2
3	H.L.-1 R.H.M.	5.3	45	2.776	----	23000	18.1	2.7	11.8
FIELD MIX PLATE SAMPLE DATA:									
3	H.L.-1 R.H.M.	4.8	45	2.835	2.911	20300	19.5	2.7	9.6
FIELD SAMPLE RECOMPACTION DATA:									
Bloomington Rd.	3 - surface 8 - binder	8.2 6.6	34 43	---- ----	---- ----	5600 8200	25+ 25+	1.5 1.7	---- ----
Hwy 401, Port Hope	4	4.7	43	----	----	11500	12.2	2.5	----
Hwy 401, Trench A	1 - surface 4 - binder	4.9 5.3	46 39	---- ----	---- ----	18400 14400	13.8 13.3	2.6 2.7	---- ----
Hwy 401, Trench B	1 - surface 4 - binder	5.2 5.2	46 42	---- ----	---- ----	17000 12500	14.2 11.8	2.4 3.1	---- ----

Table 5 **BEAM TOP LIFT PROPERTIES BEFORE AND AFTER TESTING**

BEFORE TESTING:					
Mix#	H.L. Type	Lift Thickness (mm)	B.R.D.	% Compaction	% Voids
1	4	37.4	2.300	95.4	9.7
2	8	37.6	2.318	98.3	6.4

AFTER TESTING:														
		in wheel track												*outside wheel track*
Mix#	H.L. Type	Bulk Relative Density (B.R.D.)				% Compaction of Mix Design B.R.D.				% Voids				% Compaction
		60°C	70°C	85°C	100°C	60°C	70°C	85°C	100°C	60°C	70°C	85°C	100°C	100°C
1	4	2.347	2.334	2.351	2.371	97.3	96.8	97.5	98.3	7.9	8.4	7.7	6.9	94.6
2	8	2.334	2.384	2.387	2.399	99.0	101.1	101.2	101.7	5.4	3.3	3.2	2.7	97.0

Table 6 EFFECTS OF INITIAL TEMPERATURE AND NUMBER OF PASSES ON RUTTING

Mix#	H.L. Type	Initial Temperature (°C)	Rut Depth (mm) 500 passes	1000 passes	2000 passes	4000 passes	8000 passes
1	H.L.-4	60	0.8	0.9	1.3	1.7	1.8
		70	1.8	2.2	3.0	3.3	3.6
		85	2.9	4.5	4.7	4.8	5.0
		100	5.0	6.3	6.6	6.8	6.9
2	H.L.-8	60	1.7	1.7	2.6	4.3	5.2
		70	3.7	4.7	5.2	6.8	7.8
		85	5.8	8.2	9.1	9.6	10.6
		100	9.6	11.7	15.3	15.8	17.4

Table 7 Mix #2 RUTTING COMPARISON USING DIFFERENT TYPES OF BASE LIFTS

Base Lift	Initial Temperature °C	Rut Depth (mm) 500 passes	1000 passes	2000 passes	4000 passes	8000 passes
Wood	60	1.9	2.8	3.3	3.7	4.2
	70	4.0	4.4	5.3	6.2	6.6
	75	---	---	---	---	5.3
	82.5	6.4	6.9	7.3	7.8	7.8
	100	9.8	10.5	11.3	11.6	12.0
Mix #3 H.L.-1 R.H.M.	60	---	---	---	---	---
	70	1.7	3.4	4.2	5.0	6.7
	85	5.8	7.7	8.6	9.1	9.6
	100	10.4	12.4	13.5	15.6	16.6
Mix #1 H.L.-4	60	1.7	1.7	2.6	4.3	5.2
	70	3.6	4.7	5.2	6.8	7.8
	85	5.8	8.2	9.2	9.6	10.6
	100	9.5	11.6	15.3	15.8	17.4

Fig. 1 Distribution of Bias Tire Pressures

King - Hwy 400

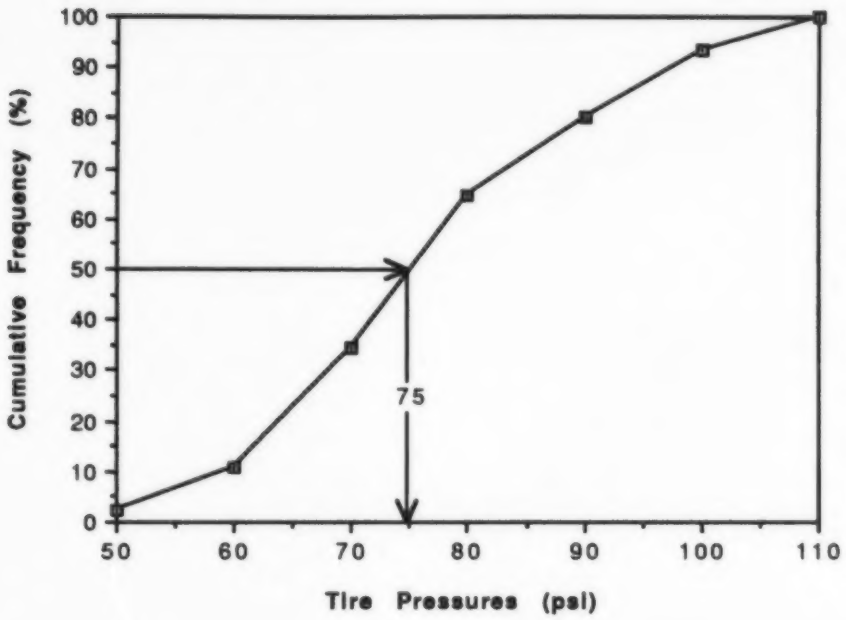
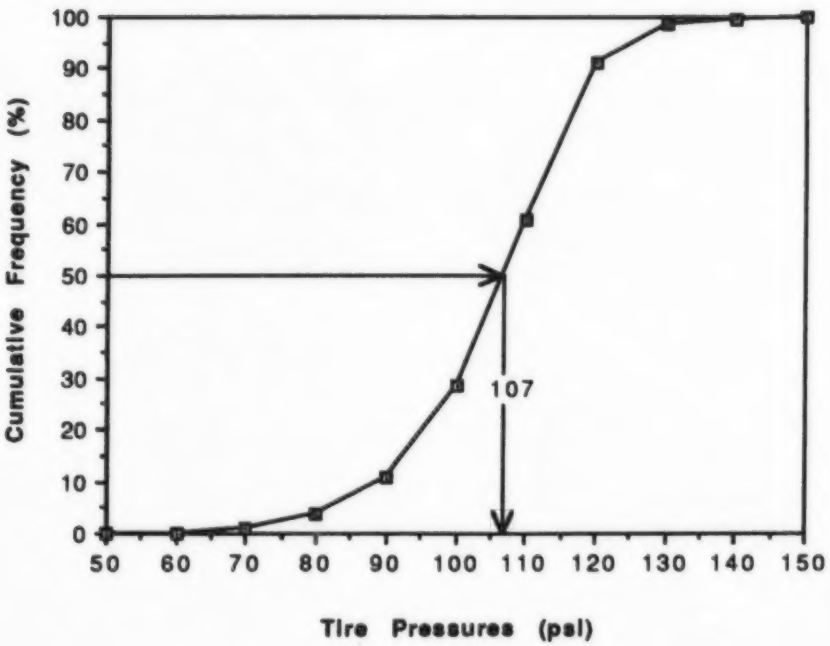


Fig. 2 Distribution of Radial Tire Pressures

Province of Ontario



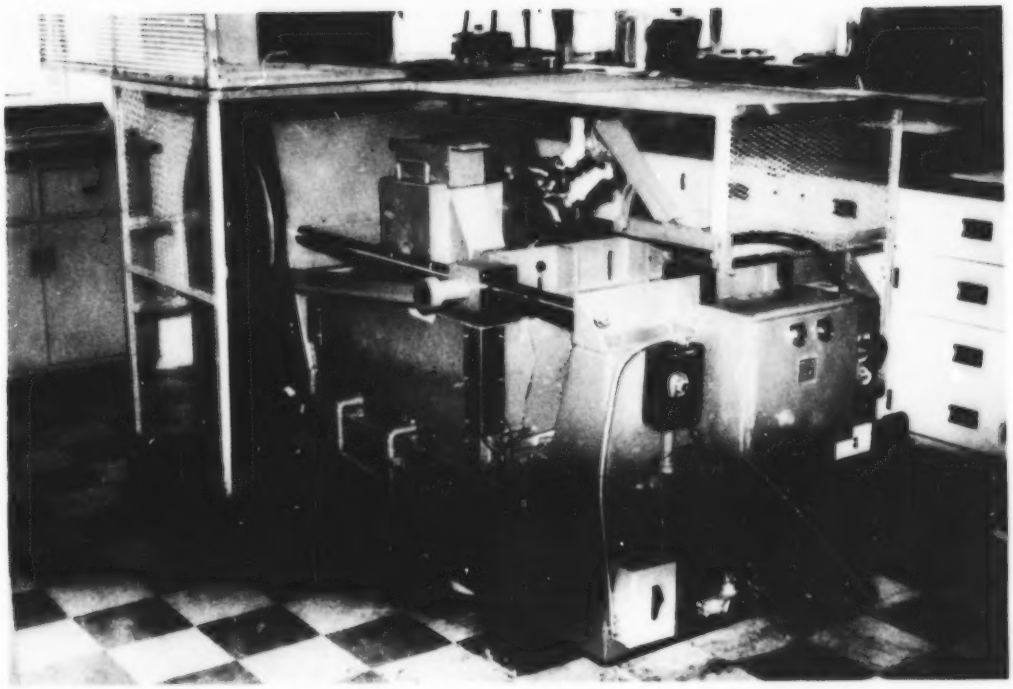
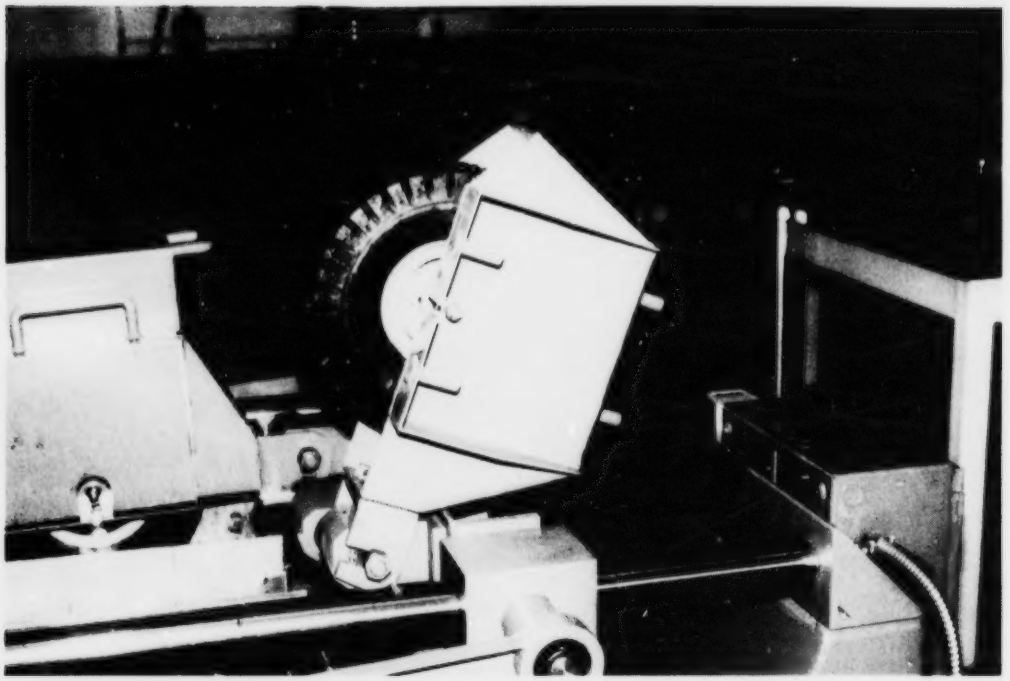


Fig. 3. Wheel Tracking Machine

(a)



(b)

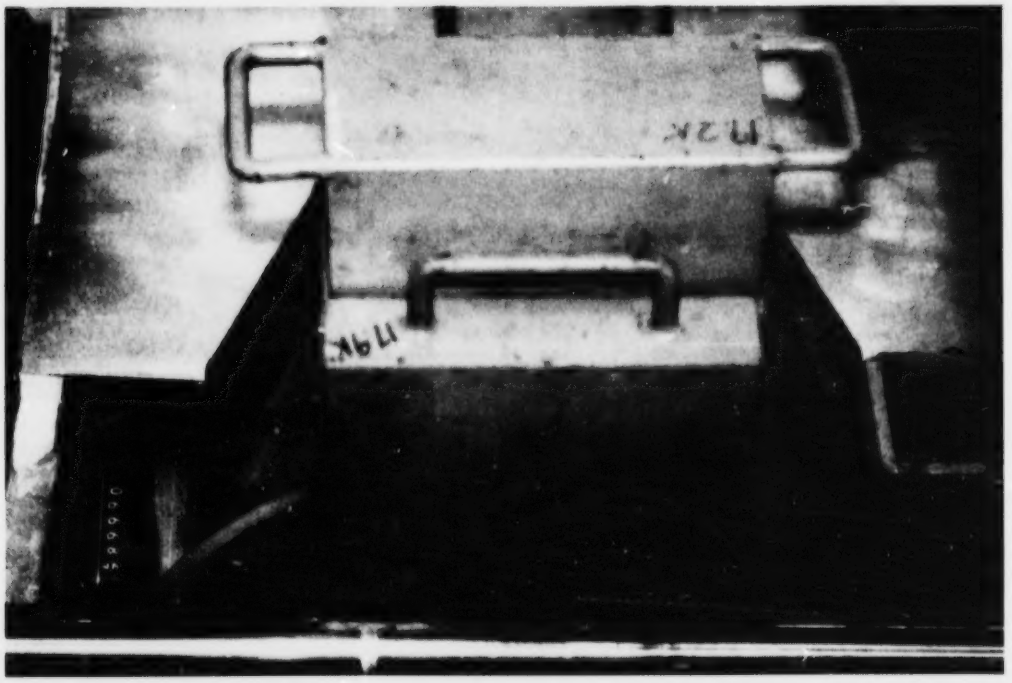


Fig. 4. Wheel Carriage Assembly Position
(a) unloaded (b) fully loaded

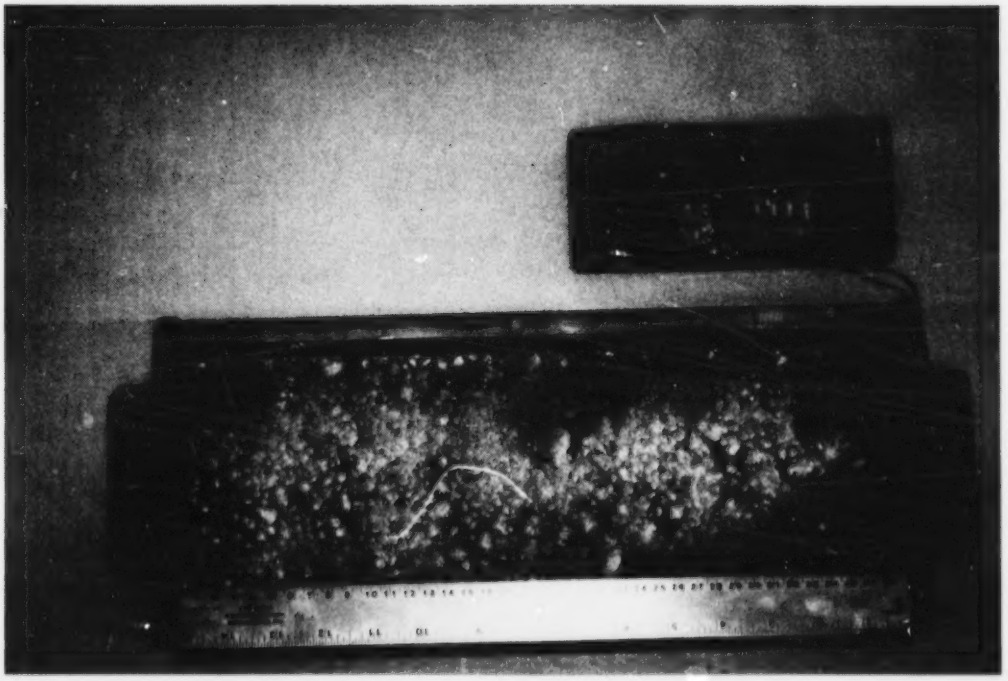


Fig. 5. Temperature Measurement Using Omega 871 Digital Thermometer with Thermocouples

Fig. 6. Surface Temperature Measurement by Raytek Raynger II Thermometer Gun

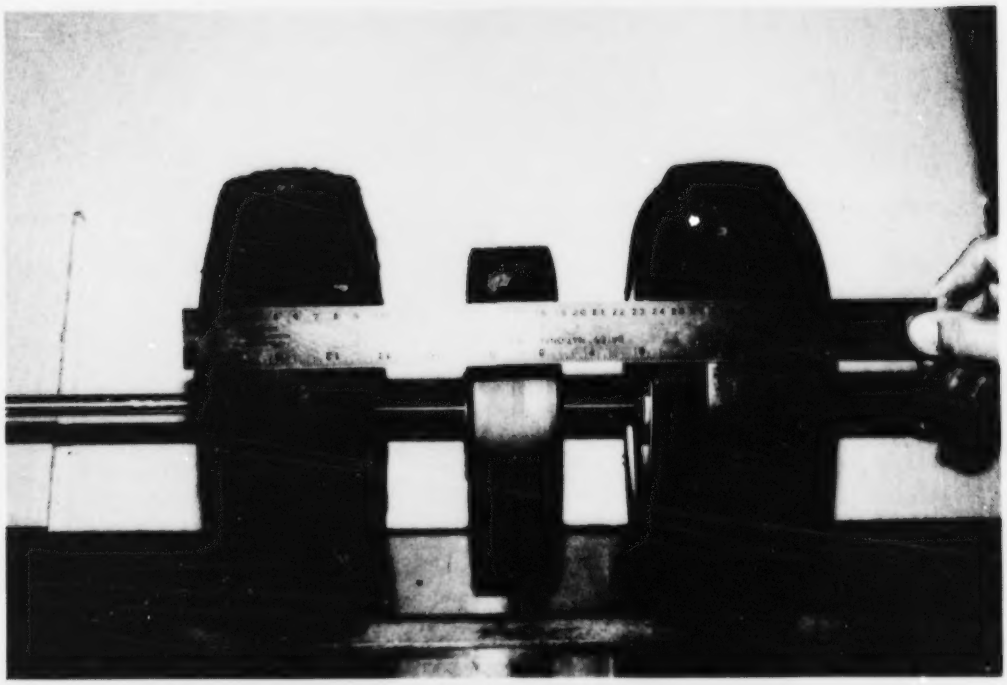
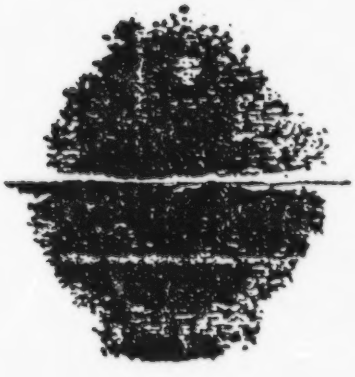


Fig. 7. **Tire Types** (left to right)
(a) treaded pneumatic
(b) solid urethane
(c) treadless pneumatic

(a)

(b)



(c)

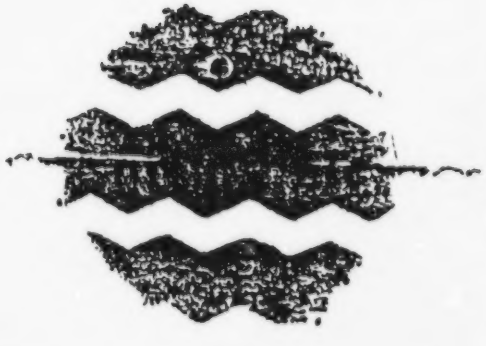


Fig. 8. Tire 'Footprints'
(a) solid urethane
(b) treadless pneumatic
(c) treaded pneumatic

Fig. 9 Change in Imprint Area with Loading for the Three Types of Tires

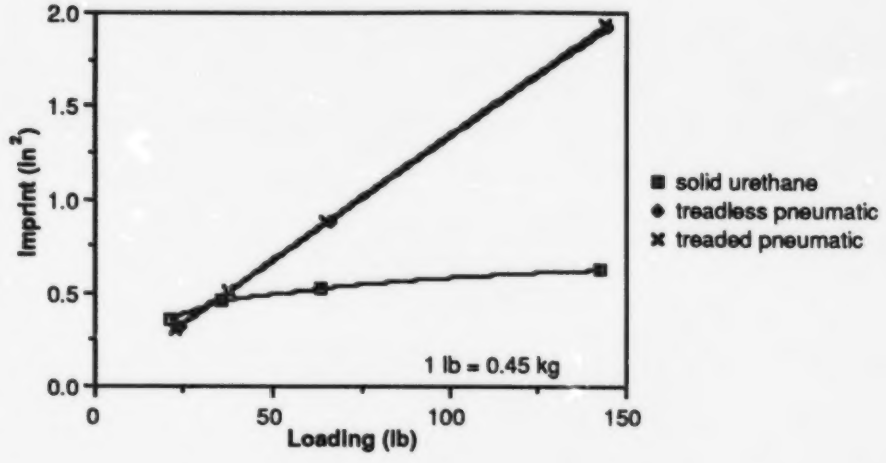


Fig. 10 Relationship of Calculated Average Effective Pressure to Loading for the Different Tire Types

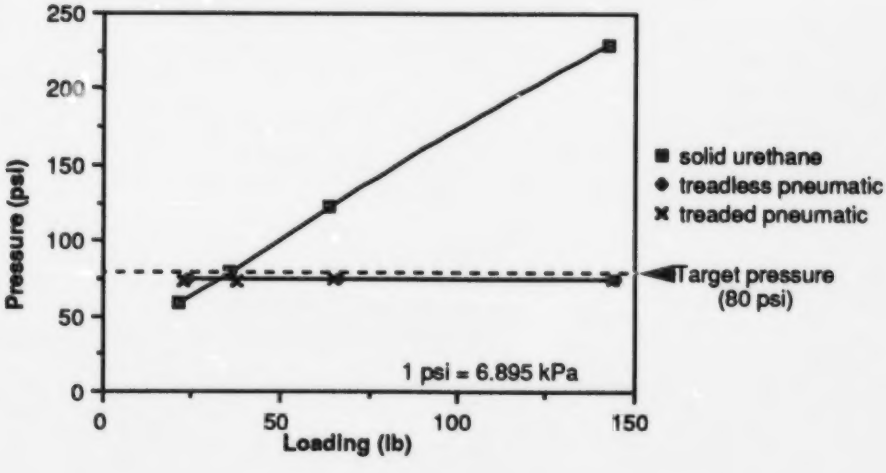
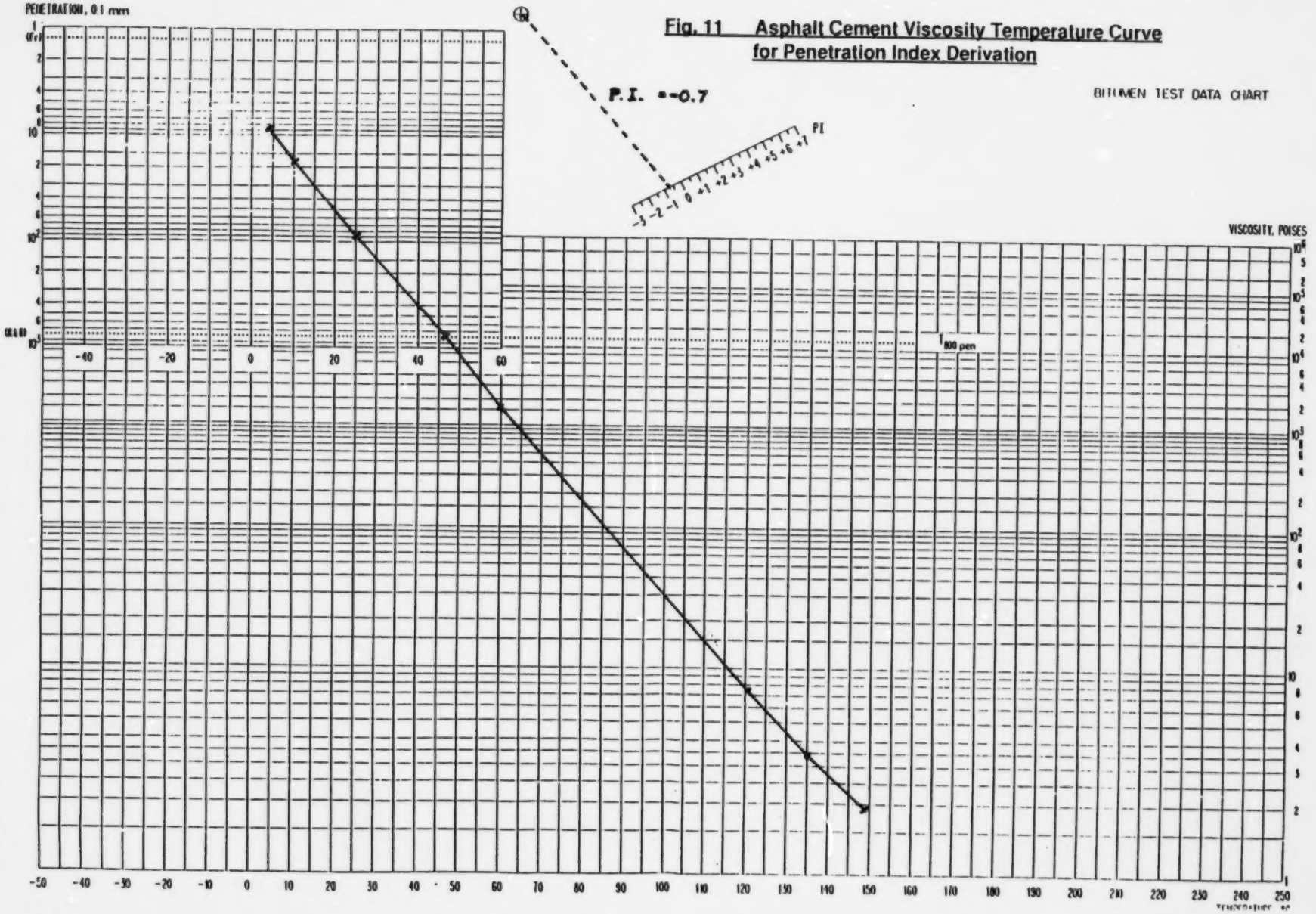


Fig. 11 Asphalt Cement Viscosity Temperature Curve for Penetration Index Derivation



69.07.206/E

Fig. 12 Temperature Profiles at Various Depths Measured at Different Time Intervals

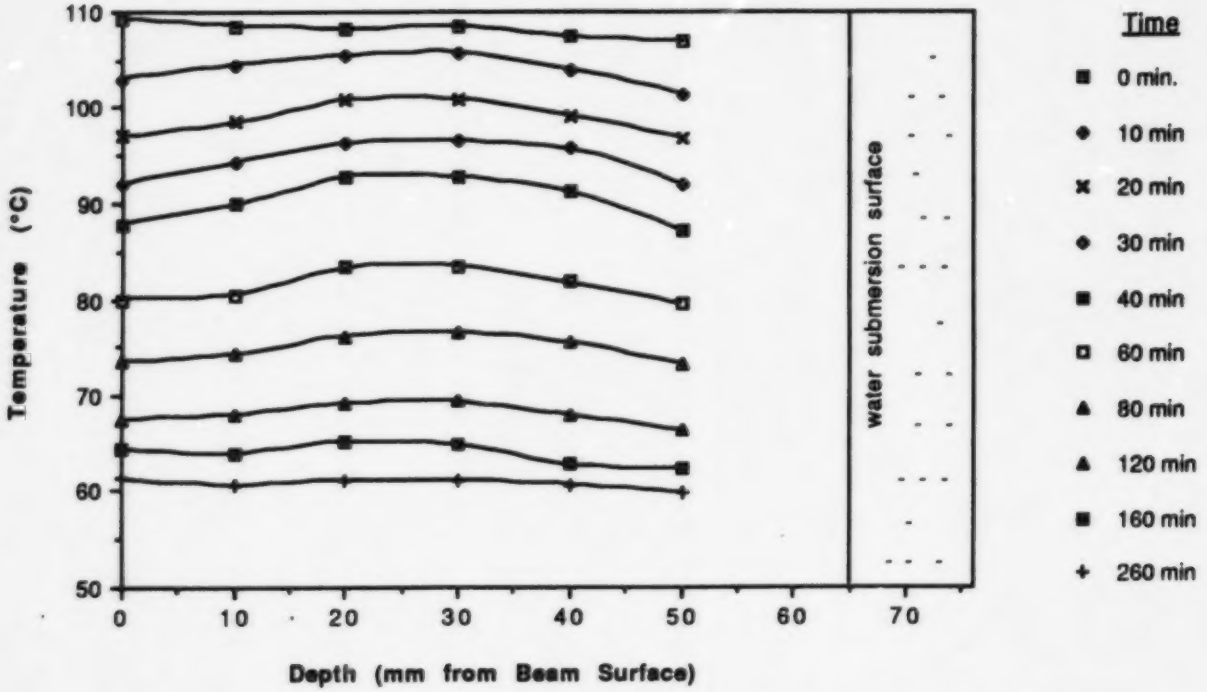
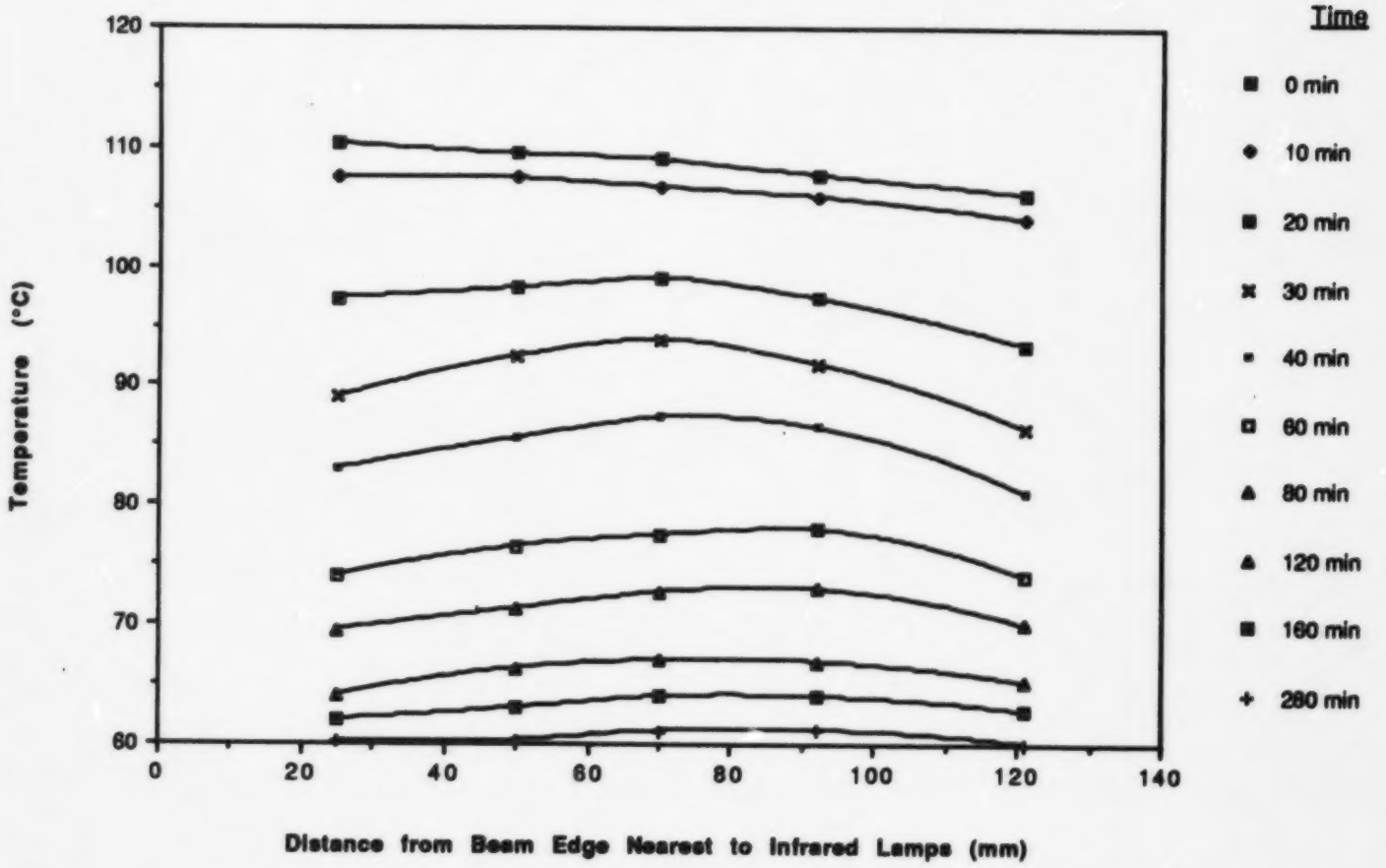
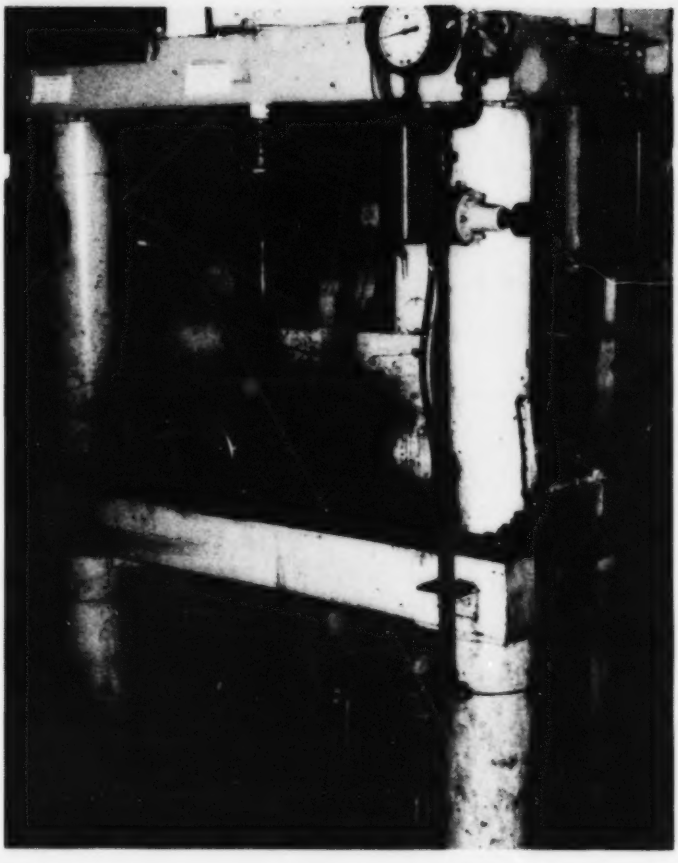
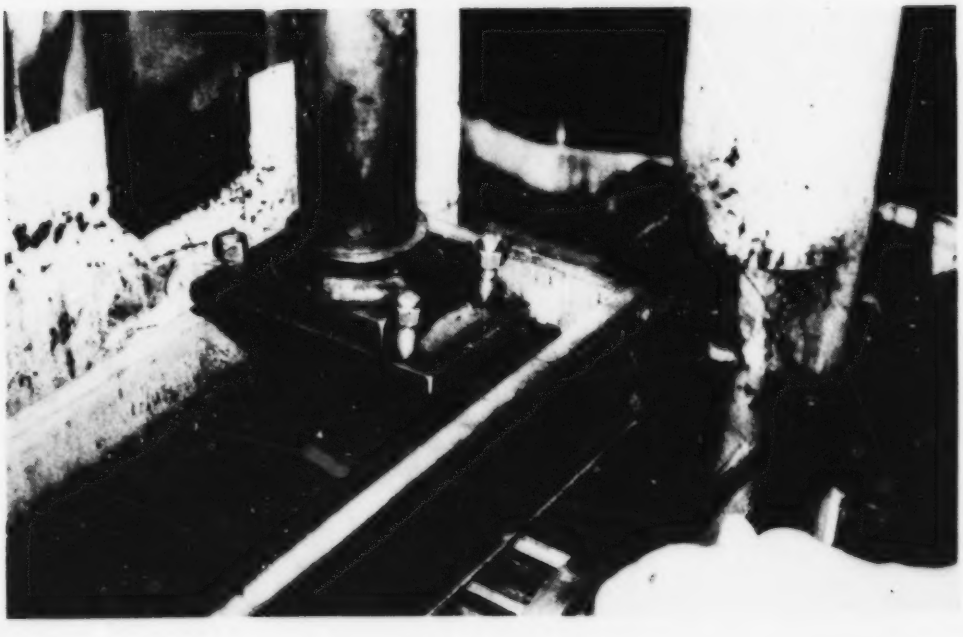


Fig. 13 Beam Temperature Profiles @ 30 mm Depth at Various Locations Along the Beam Width





(a)



(b)

Fig. 14. Modified California Kneading Compactor (a) mould and platform (b) tamping foot

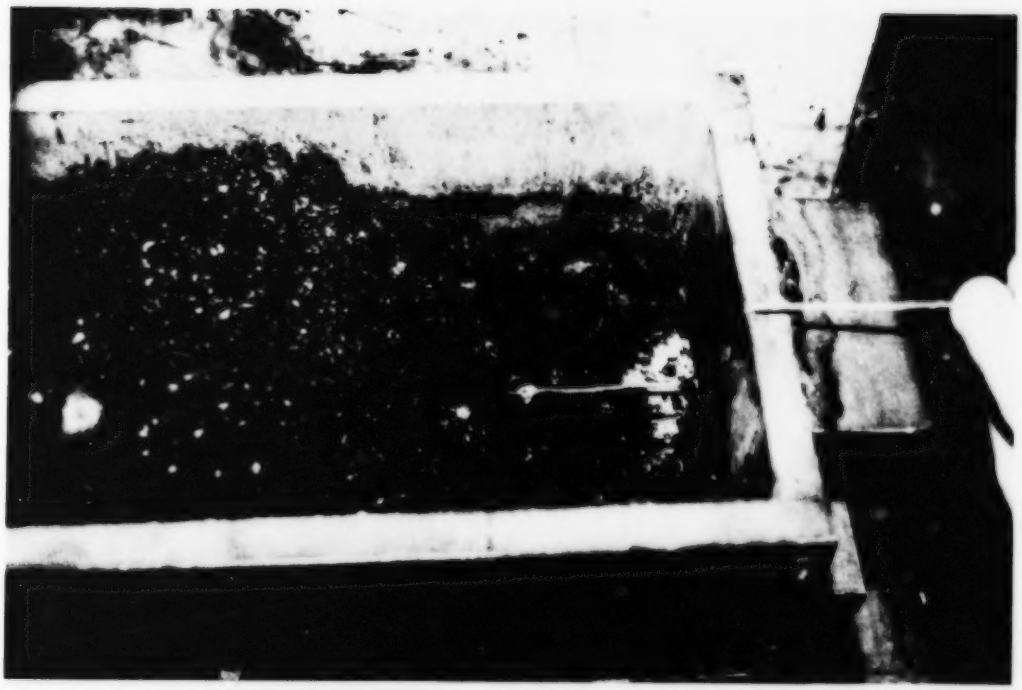
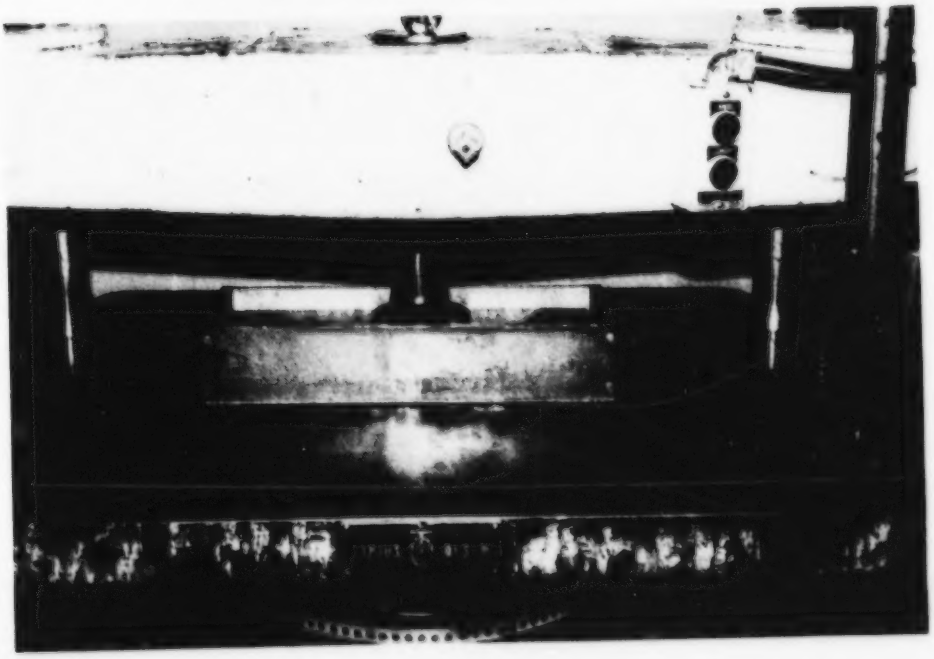


Fig. 15. Placement of a Thermocouple

(a)



(b)

Fig. 16. Tinius Olsen Compression Machine
(a) controls (b) levelling load application

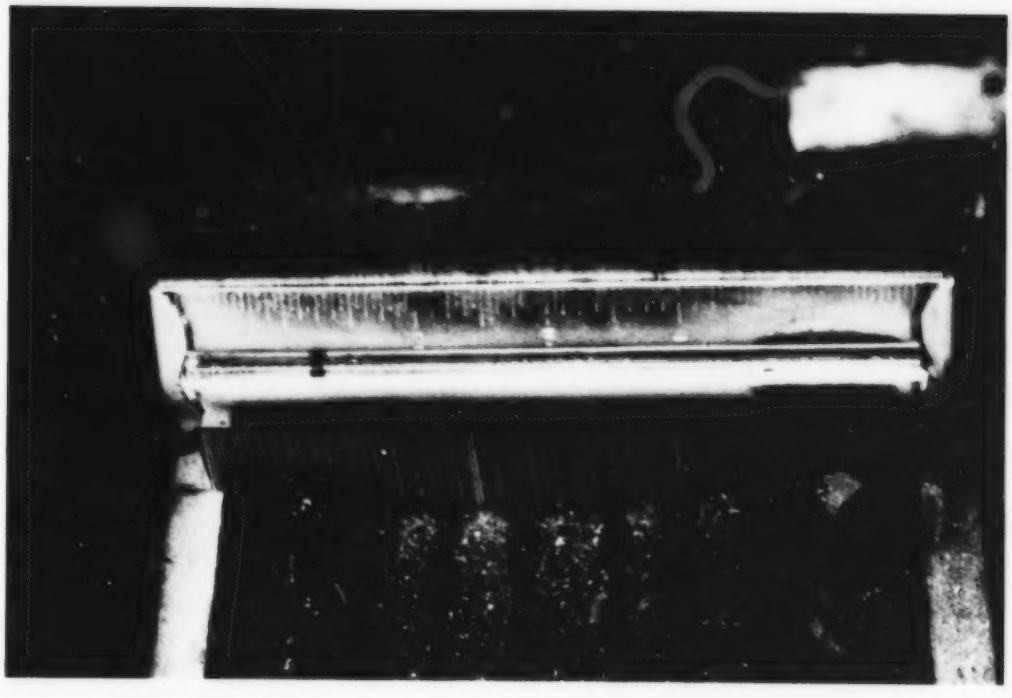


Fig. 17. Profile and Rutting Depth Measurement

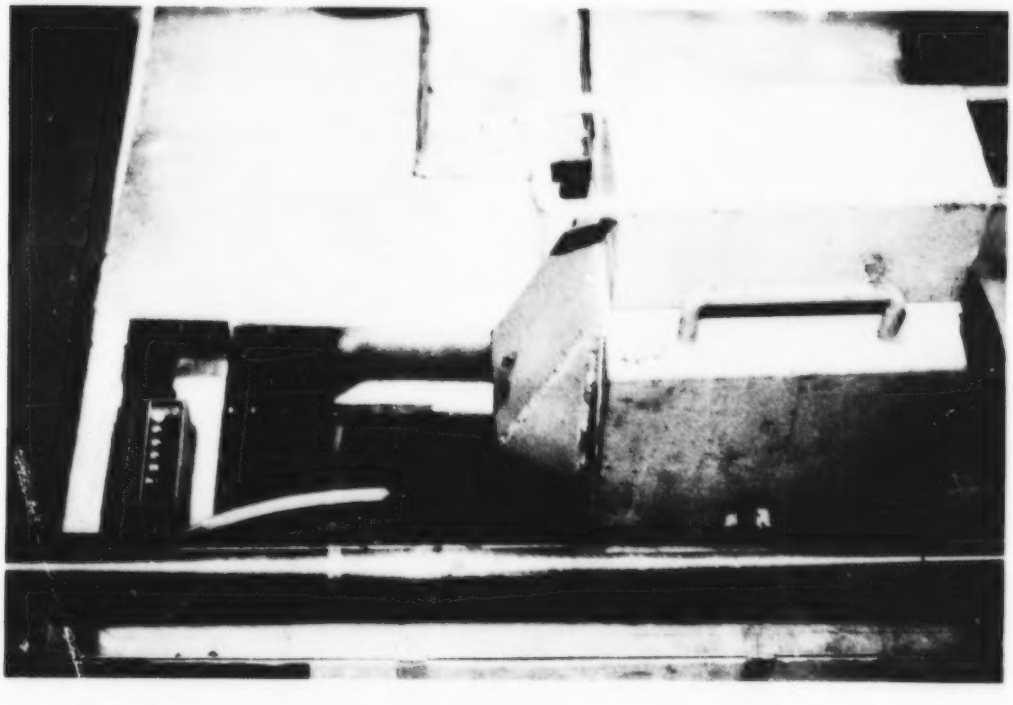
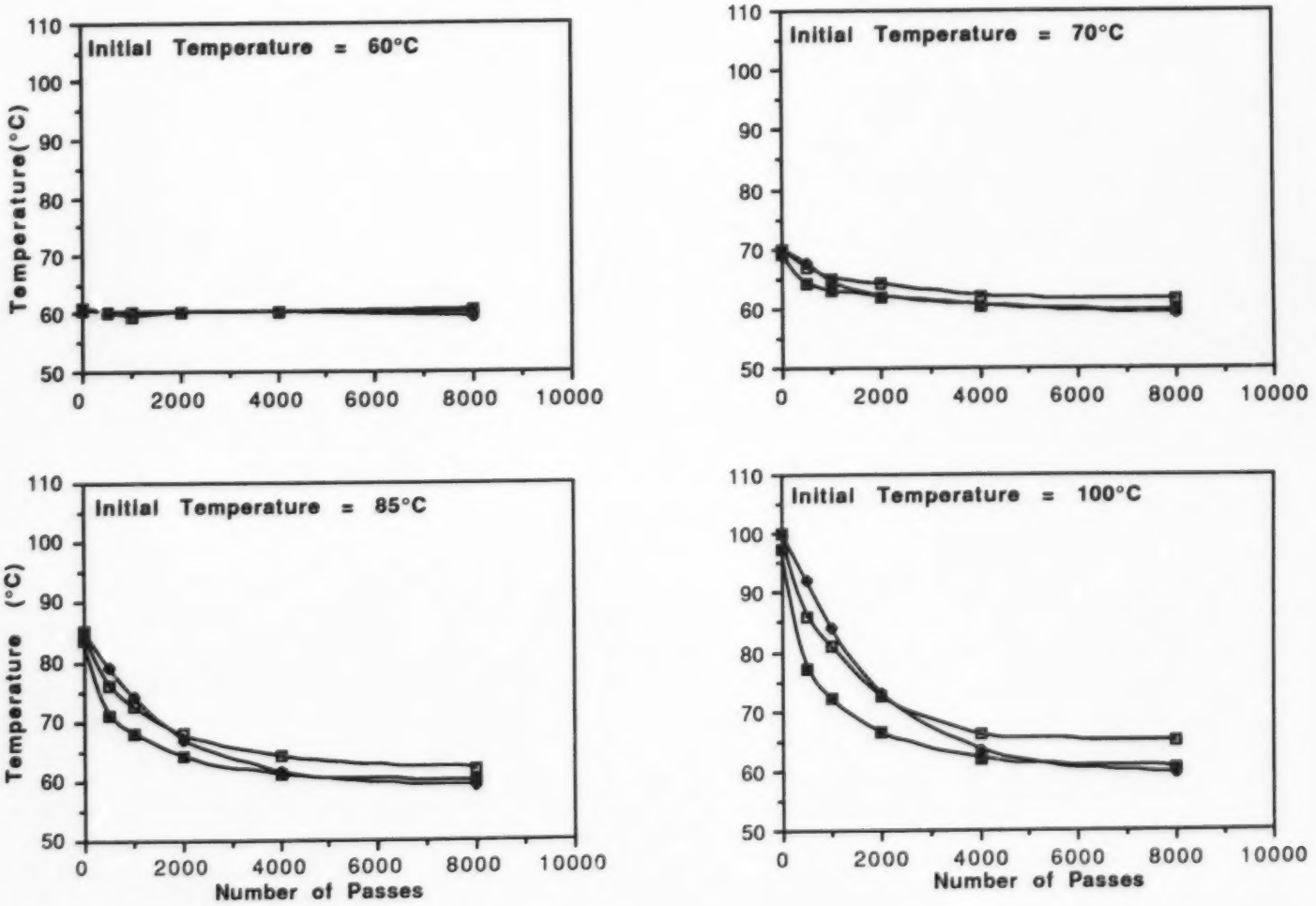


Fig. 18. Cycle Counter and W.T.M. Beam Set-Up

Fig. 19 Change of Temperature Gradient with Number of Passes For Different Initial Sample Temperatures

(▫ Surface; ◆ Interface; ■ Base)



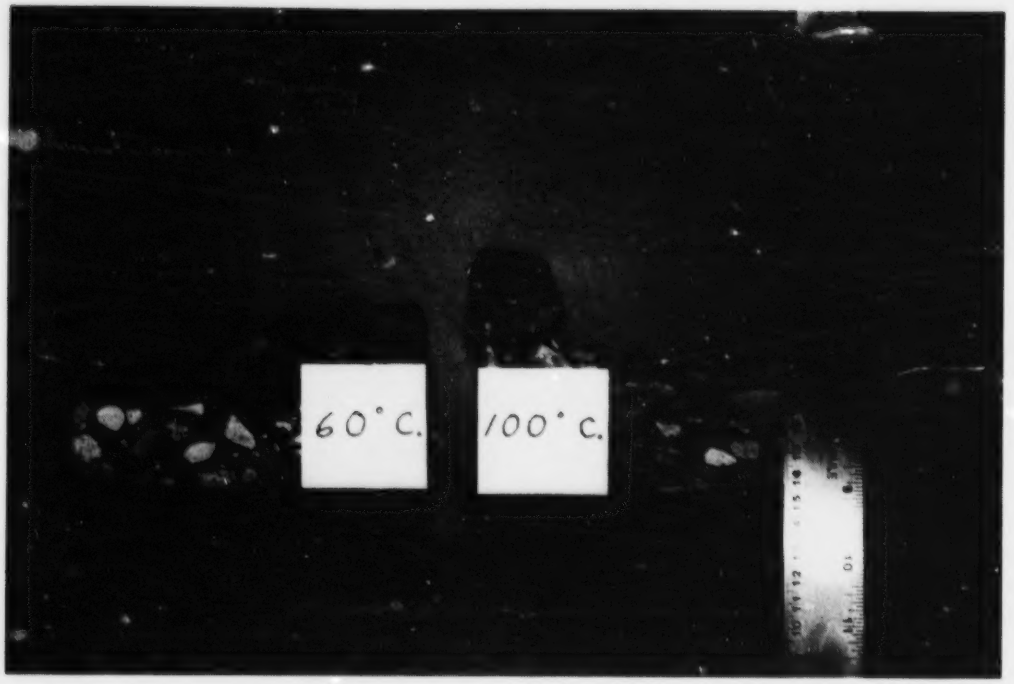


Fig. 20. Cross-Sections of H.L.-8 Mix After 8 000 Passes at 60°C and 100°C

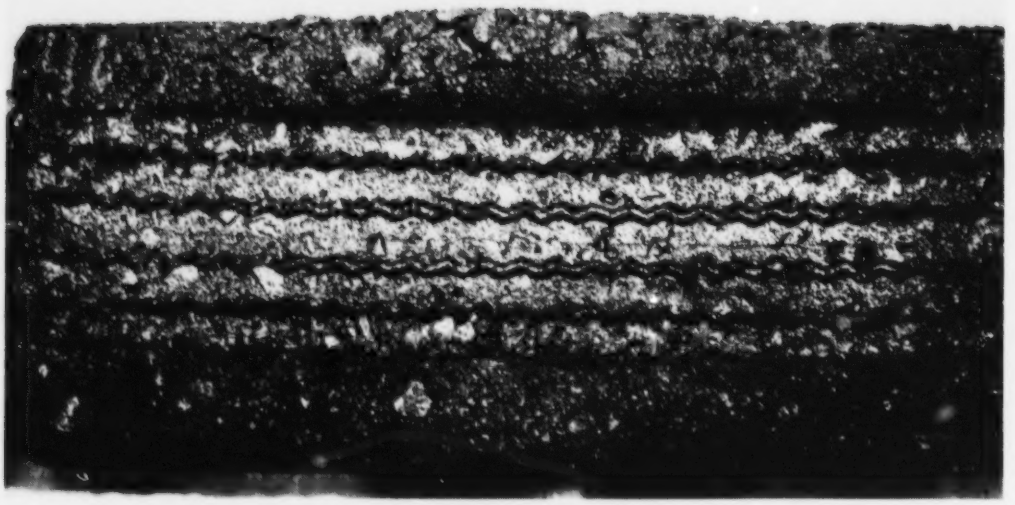


Fig. 21. Characteristics of Badly Rutted Beams
- random hairline cracking adjacent to tire track
- increasing height adjacent to tire track
- bleeding of A.C. in tire track

Fig. 22 Response of Mix #1 to Rutting Under Different Types of Tires After 10000 Passes by Constant Temperature Mode Testing

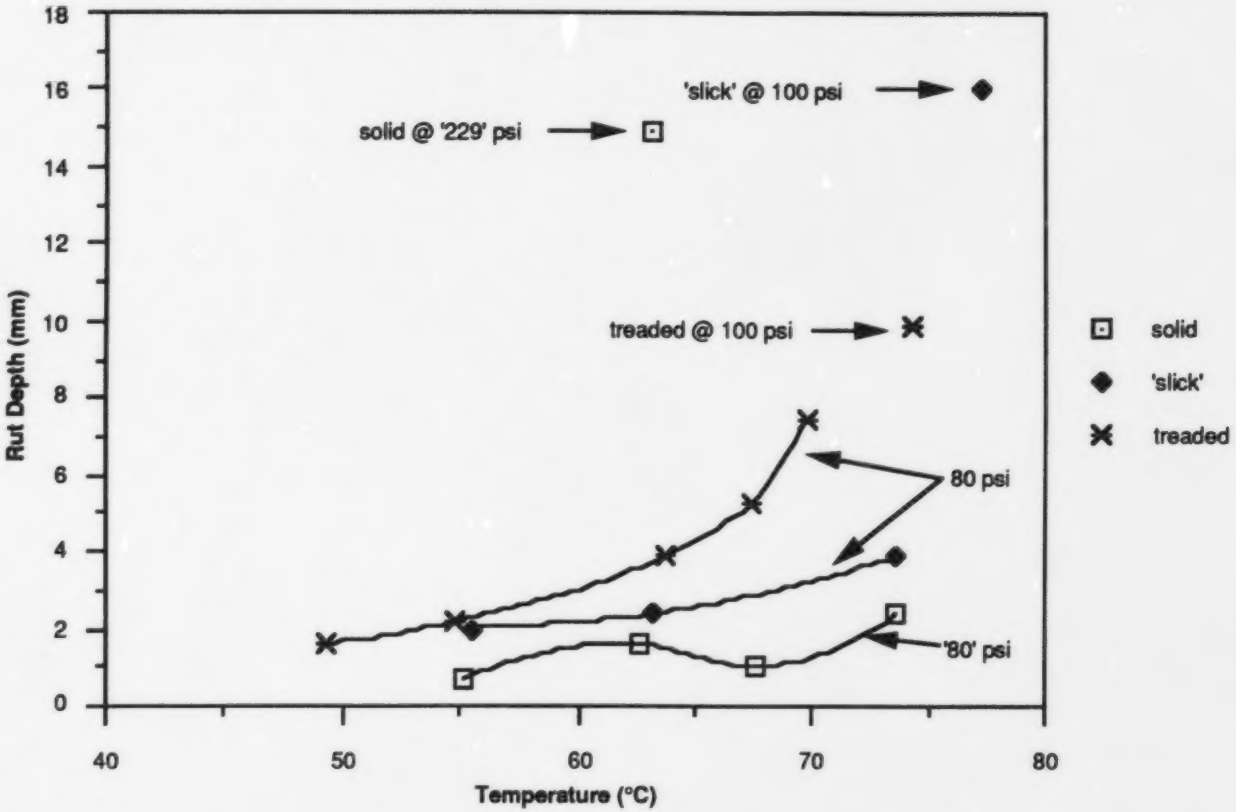


Fig. 23 Rut Depth vs Number of Passes at Different Initial Temperatures for an H.L.-4 Mix

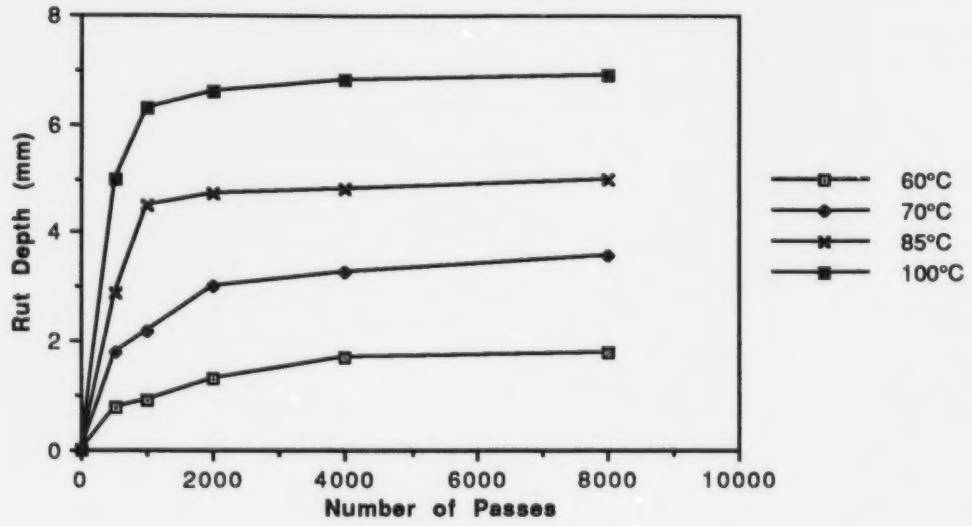


Fig. 24 Rut Depth vs Number of Passes at Different Initial Temperatures for an H.L.-8 Mix

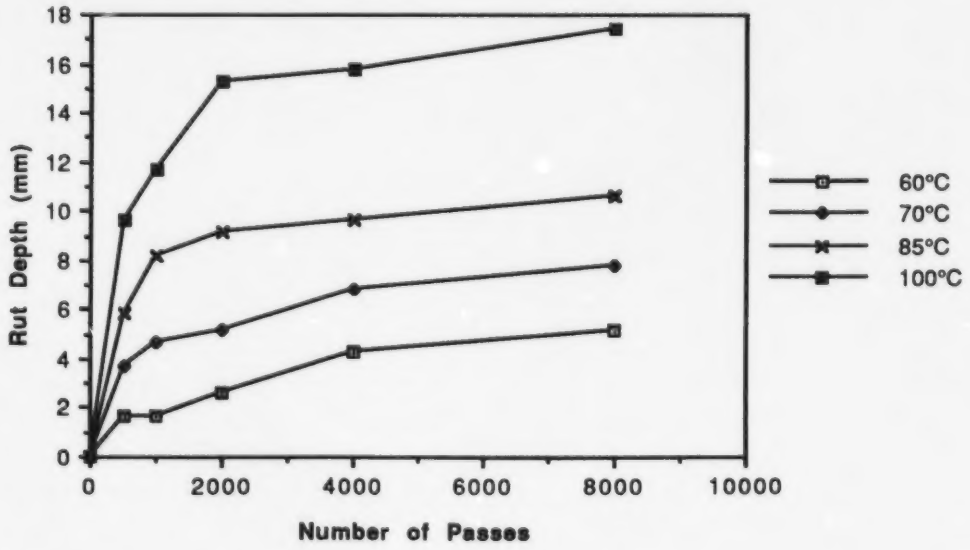
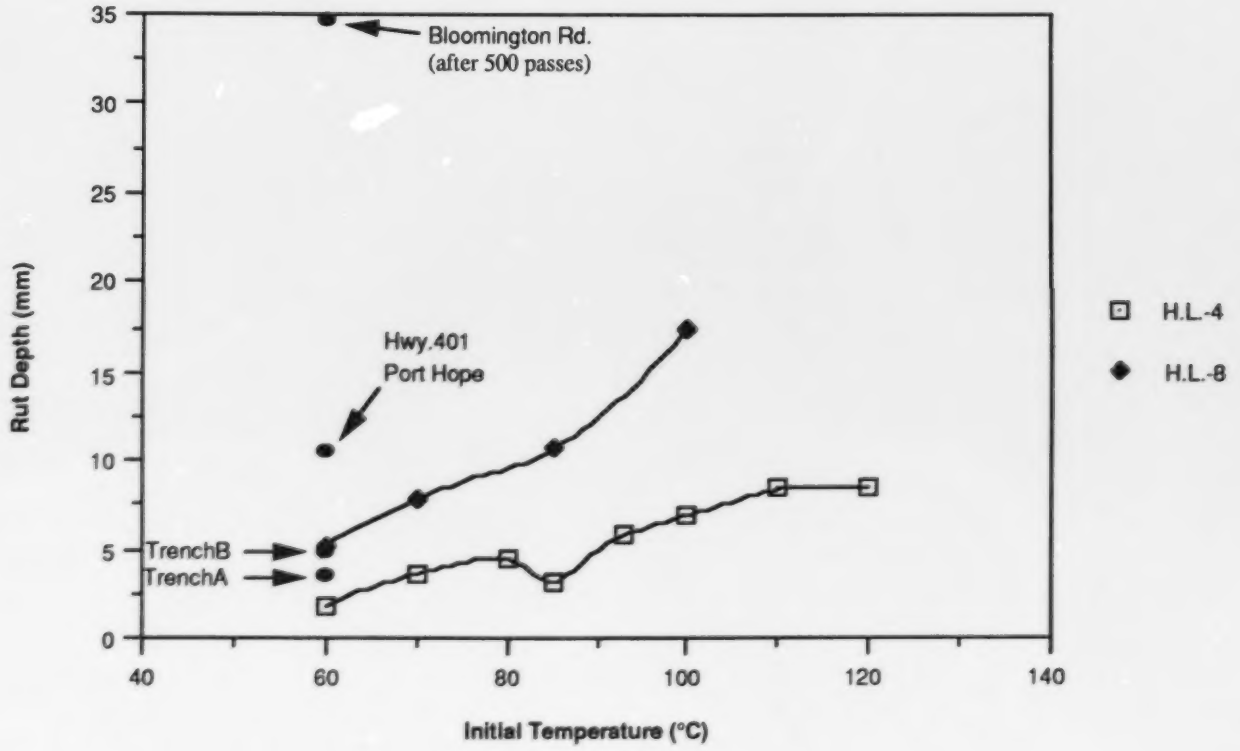
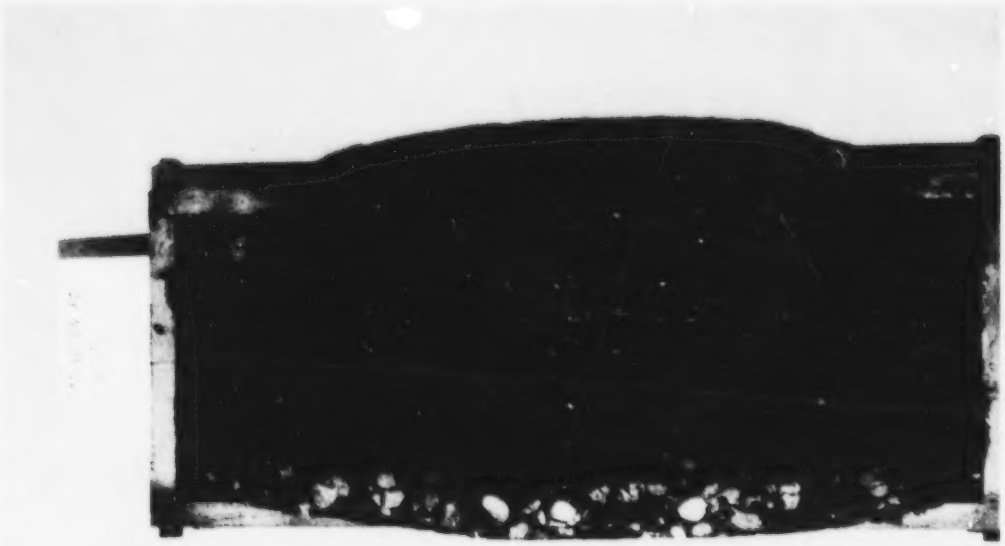
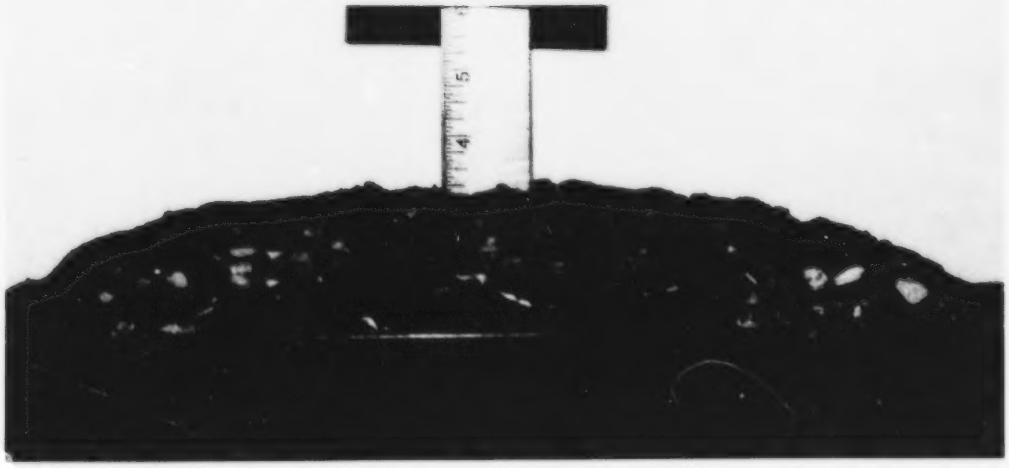


Fig. 25 Field and Laboratory Mix Rutting After 8000 Passes at Different Initial Temperatures





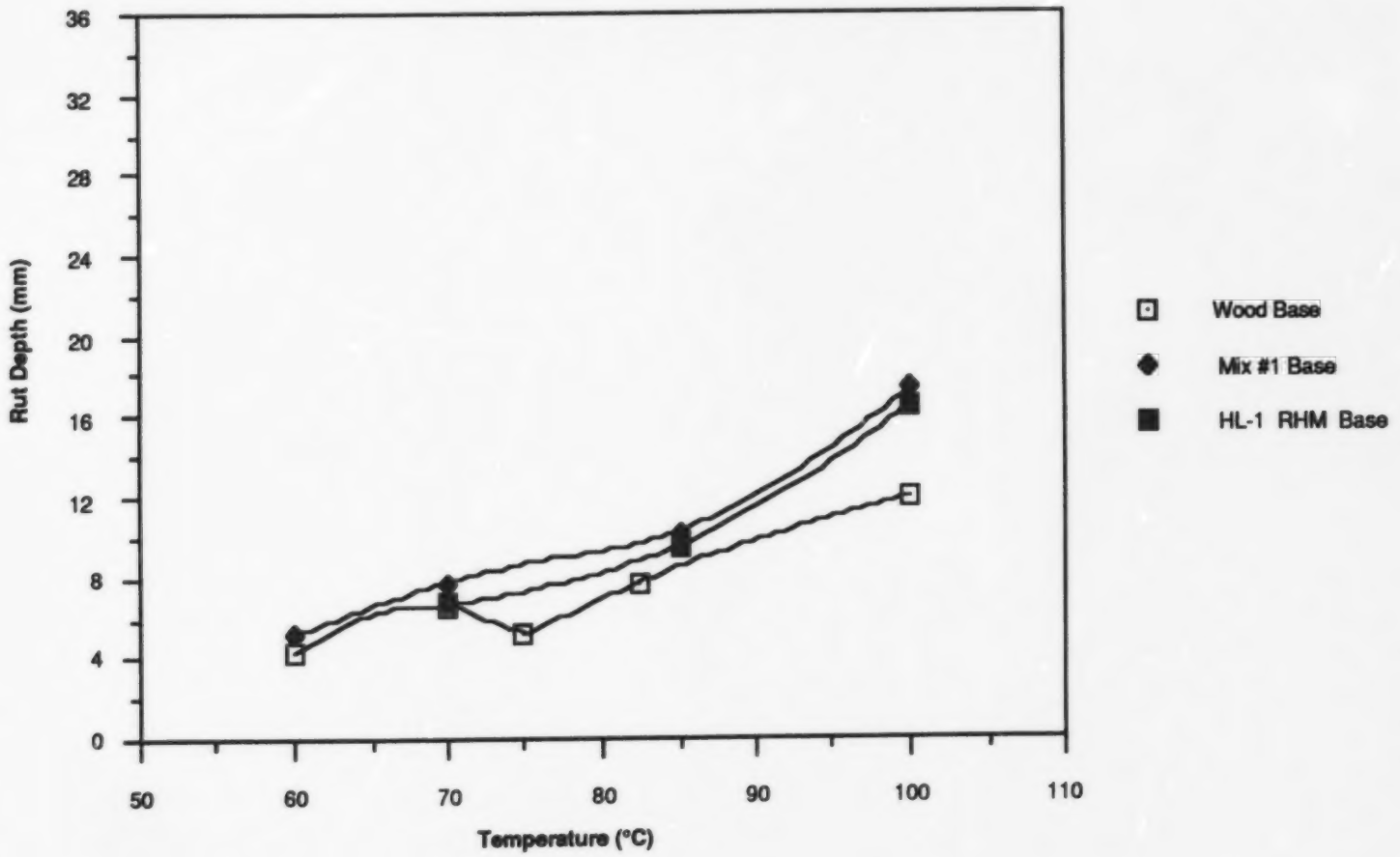
(a)



(b)

Fig. 26. Bloomington Rd. Field Sample After Testing
(a) plan view (b) side view

Fig. 27 Effects of Different Types of Base Lifts on Mix #2 Rutting



APPENDIX A

WEIGHT RESTRICTION BY WIDTH OF TIRES

(a) Vehicles equipped with tires of less than 150 mm in width shall not be operated on a highway where the weight upon any millimetre in the width of the tire exceeds 9 kg.

or

(b) Vehicles equipped with tires of 150 mm or more in width shall not be operated on a highway where the weight upon any millimetre in the width exceeds 11 kg.

Example:

Tire size 11.00 x 22
Tire tread width = 11 inches
11 inches = 279.4 mm
279.4 mm x 11 kg = 3073.4 kg
Maximum weight on tire = 3073.4 kg

APPENDIX B

Test Method for

ACCELERATED RUTTING OF BITUMINOUS MIXTURES USING A WHEEL TRACKING MACHINE (W.T.M.)

1. Scope

1.1 This method covers the preparation and testing of laboratory compacted beams using a Wheel Tracking Machine. Rut testing may be carried out by either the Constant Temperature Mode or the Decreasing Temperature Mode.

2. Applicable Documents

2.1 *ASTM Standards*

D1559 Resistance to Plastic Flow of Bituminous Mixtures Using Marshall Apparatus
D1561 Method of Preparation of Bituminous Mixture Test Specimens by Means of California Kneading Compactor
D2041 Theoretical Maximum Specific Gravity of Bituminous Paving Mixture
D2726 Test Method for Bulk Specific Gravity of Compacted Bituminous Mixtures Using Saturated Surface-Dry Specimens
D3203 Percent Air Voids in Compacted Dense and Open Bituminous Paving Mixtures

2.2 *MTO Standards*

Method for Design of Bituminous Mixes, April, 1986, Engineering Materials Office Laboratory Standard Manual

3. Description of Terms

3.1 Decreasing Temperature Mode - A method of testing in which a manufactured beam is tested while cooling to a lower temperature.

3.2 Constant Temperature Mode - A method of testing in which a manufactured beam is tested at a constant temperature.

4. Summary of Method

4.1 Two batches of mix, each approximately 4 700 g, are compacted in two separate layers into a beam 381 mm in length x 140 mm in width x 76 mm in thickness (15 x $5\frac{1}{2}$ x 3 in). The target compaction of each layer is 96 ± 1% of the Marshall density as determined by D1559. Rutting is carried out using a W.T.M. at a loading of 65.5 kg (144.4 lb) and a tire pressure of 550 kPa (80 psi). Rut depth measurements from the original level of the beam transverse profile, i.e. perpendicular to the wheel track, is periodically recorded using a profilometer gauge.

5. Significance and Use

5.1 The test is used to identify mixes in the laboratory with rutting resistance potential at the mix design stage; this could avoid the costly repairs of using unstable mixes which rut under heavy traffic loads. The test method may be adapted for testing pavement samples from the field.

6. Apparatus

6.1 Wheel Tracking Machine:

6.1.1 Water reservoir with temperature control within ± 2.5°C of the required temperature.

6.1.2 Infrared lamps which maintain the entire beam surface within ± 1°C of the required temperature.

6.1.3 Test tire is a 4.10 - 4 treaded pneumatic tire inflated to 550 kPa (80 psi) pressure with a 4 ply rating and a Shore durometer hardness of 70. The tire tread width is 70 mm ($2\frac{3}{4}$ in).

6.1.4 A total of 65.5 kg or 144.4 lb (tire and weights) load on the specimen.

6.2 California kneading compactor - conforming with A.S.T.M. D1561, but with a modified rectangular tamping foot with dimensions of 133 mm x 76 mm x 19 mm ($5\frac{1}{4}$ x 3 x $\frac{3}{4}$ in).

6.3 Compression testing machine - with a minimum capacity of 222 kN (50 000 lb f).

6.4 Forced air oven and hot plate - thermostatically controlled oven and hot plate to heat and maintain materials to required temperatures ± 2.8°C.

6.5 Balance - 16 kg capacity, sensitive to 0.1 g.

6.6 Temperature measuring devices:

6.6.1 Electronic device capable of being connected to fine gauge thermocouples and sensitive to 0.1°C, e.g., Omega 871 Digital thermometer with fine gauge chromel-alumel thermocouples.

6.6.2 Fast acting surface temperature measuring device sensitive to 0.1°C, e.g., Raytek Raynger II non-contact infrared themometer gun.

6.7 Steel moulds - with inside dimensions of 381 mm length x 140 mm width x 76 mm heighth (15 x $5\frac{1}{2}$ x 3 in). Each mould is numbered and marked, full width, directly under the middle and endpoints of wheel axle travel when the mould is set in the W.T.M., for a total of 3 designated points.

6.8 Levelling plate - with dimensions of 380 mm x 137 mm x 13 mm (15 x $5\frac{1}{2}$ x $\frac{1}{2}$ in).

6.9 Profilometers - three profilometers with measuring widths of 152 mm (6 in) minimum.

6.10 Insulation - sufficient to completely surround steel moulds. Cellulose fibre, fibreglass bats, or styrofoam are suitable for this purpose.

6.11 Miscellaneous - masking tape, 127 mm (5 in) wide stiff scraper, and aluminium foil.

7. Specimen Preparation

7.1 *Compaction of Bottom Lift:*

7.1.1 Batch the aggregates to designed gradation and sufficient (approximately 4 500 g of aggregate) to make up a lift thickness of 38 mm ($1\frac{1}{2}$ in). Place the aggregates in a forced air oven overnight at 170°C.

7.1.2 Pour the aggregates into a mechanical mixer and dry mix for 15 seconds; then add the predetermined mass of asphalt cement and mix for a further 45 seconds or longer until all particles are thoroughly coated. Cover the mix with aluminium foil and place in the forced air oven until the mix is reheated to a temperature of 168°C (approximately 45 to 60 minutes).

7.1.3 Position a preheated beam mould from the forced air oven on the California kneading compactor. Place a thermocouple on the bottom of the mould, 70 mm ($2\frac{3}{4}$ in) from any side and with the thermocouple connection accessible at one end of the mould.

7.1.4 Spread the mix evenly in the mould and rod perpendicular to the beam length with a wide scraper to improve mix homogeneity.

7.1.5 Compact the mix to produce a target compaction of 96 ± 1% of the Marshall density as determined by the A.S.T.M. D1559 method. A California kneading compactor is employed for beam production and beam densities are measured according to the A.S.T.M. D2726. The compactive effort is determined by trial and error using the procedure in the A.S.T.M. D1561 as a guide.

Example: For an H.L.-4 mix with 55% by mass of the aggregate passing the 4.75 mm sieve, a mix which has been used as a standard base mix (by the Ministry of Transportation of Ontario), the following compaction sequence is employed to obtain the target compaction:

1) - 40 tamps @ 425 kPa (62 psi);
2) - 40 tamps @ 505 kPa (73 psi);
3) - 40 tamps @ 895 kPa (130 psi);
4) - 60 tamps @ 1 345 kPa (195 psi).

7.1.6 Transfer the mould with the compacted mix to the compression machine. Remove the preheated levelling plate from the oven and place on top of the lift. Apply a loading of 146 800 N at a rate

of 6.4 mm ($\frac{1}{4}$ in) per minute and maintain at this level for a period of one minute before releasing slowly to zero.

7.1.7 Allow the compacted sample to cool overnight in the mould.

7.2 *Compaction of Top Lift:*

7.2.1 Follow the procedure as outlined in sections 7.1.1 and 7.1.2. Then place the cold beam mould with the compacted base lift in position on the California kneading compactor.

7.2.2 Spread a small portion of mix on top of the base lift to hold a thermocouple in place 6 mm ($\frac{1}{4}$ in) above the base lift and 70 mm ($2\frac{3}{4}$ in) from any side with the thermocouple connection accessible at one end of the mould. Spread the remainder of the mix evenly in the mould and rod as in section 7.1.4.

7.2.3 Follow the procedure of sections 7.1.5 and 7.1.6 using the same compaction and compression pressures as outlined for the standard base mix. For each new top mix being considered, one spare specimen must be made. The spare specimen is used for adjusting the loaded wheel carriage level of the W.T.M. as outlined in section 9.3 and for determining the lift densities and percent compactions of the top and base lifts after separation by sawing.

METHOD A - DECREASING TEMPERATURE MODE (D.T.M.)

8. Initial Test Temperature

8.1 70°C, 85°C or 100°C are suggested as initial test temperatures. A temperature of 60°C can be included as one of the initial test temperatures and testing is to be performed according to the D.T.M. procedure. For each of the temperatures, the W.T.M. constant temperature environment is set at 60°C; if the beam interface thermocouple temperature drops below 60°C, a slightly higher environmental temperature may be required.

9. W.T.M Preparation

9.1 Adjust the W.T.M. water level such that the final level is 13 ± 3 mm ($\frac{1}{2} \pm \frac{1}{8}$ in) above the mould bottom. Switch on the bath heaters and the circulating pump and maintain the surrounding water at 60°C.

9.2 The rheostat for the infrared lamps is adjusted to produce a beam surface temperature of 60°C.

9.3 A total loading of 65.5 kg (144.4 lb), inclusive of the tire, the carriage assembly and a full complement of weights, is placed on the surface of the spare specimen mentioned in section 7.2.3. Ensure that the loaded wheel carriage is level by using a spirit level and adjust if it is found necessary.

10. Beam Profiles

10.1 Place masking tape across the total width of the mould at the three predetermined points, i.e., the middle and endpoints of W.T.M. wheel travel (254 mm or 10 in between the endpoints). Press the profilometers firmly on the tape to record the three profiles at the exact locations. Remove the tape. Transfer the profiles onto a worksheet using a fine ball point pen or sharp pencil.

11. Beam Conditioning

11.1 When the temperature indicated by the thermocouple between the lifts drops below the required initial test temperature, cover the beam with the levelling plate and place the mould assembly back in a forced air oven with the temperature set 10 C° higher than the required initial test temperature.

11.2 Remove the assembly from the oven before overheating and cover with an insulating layer to ensure even heat distribution throughout the beam.

11.3 When the interface temperature is approximately 2 C° above the required test temperature, insulate the mould sides with styrofoam.

12. Test Procedure

12.1 When all beam temperature readings (surface, interface, and base) are within 1 C° of the test temperature, place the insulated mould in the W.T.M. Secure the mould to eliminate any movement under the action of the wheel. Record all temperature readings and start the testing.

12.2 Stop the machine after 500 passes (250 cycles) to record all beam temperature readings. Take the transverse profiles of the beam at the three points designated in section 10.1 before restarting the W.T.M. Transfer the outlines obtained to the worksheet, superimposing the profiles onto the corresponding initial profiles. Repeat this procedure at 1 000 and 2 000 passes.

NOTE 1—*Stoppage at 500, 1 000, and 2 000 passes may be omitted if a complete specimen rutting history is not required.*

12.3 After 4 000 passes, obtain the profiles as in section 12.2 and discontinue the test. Remove the specimen from the W.T.M. and obtain a longitudinal rutting profile along the centreline of the wheel track. Allow the specimen to cool overnight before carefully extruding from the mould.

12.4 Separate the two lifts by sawing. Further separation of the top lift may be done to obtain portions of the sample under and adjacent to the wheel track. Determine the bulk relative density, percent compaction, and percent voids by A.S.T.M. D2726 for the different portions.

13. Determination of Average Rut

13.1 Draw, on metric graph paper, a straight line representing the longitudinal edge of the mould surface.

13.2 From the worksheet, measure the height differences between the mould surface and the initial profiles at the three predetermined points as specified in section 10.1 and transfer these differences to the appropriate positions on the graph for each of the three locations. Join the three points to produce the initial profile line on the graph paper.

13.3 Similarly, plot the final profile height differences at the three predetermined positions onto the graph.

13.4 Use the profilometers to obtain a longitudinal profile of the specimen along the centreline of the wheel track and superimpose this profile onto the three final profile points of the graph as determined in section 13.3.

13.5 Measure, by planimeter, the rutted area in square millimetres (square inches) as defined by the initial and final profile lines within the three points. Divide this quantity by the length of wheel travel, i.e., 254 mm (10 in), to obtain the average rut depth.

14. Report

14.1 The report shall include the following:

14.1.1 Mode of testing.

14.1.2 Test temperature.

14.1.3 Identification of the top and bottom (base) mixes.

14.1.4 Rut Depth to 0.1 mm after 500, 1 000, 2 000 and 4 000 passes.

14.1.5 Average rut depth.

14.2 Other information that may be of relevance includes:

14.2.1 Bulk relative density of the top and bottom mixes before testing.

14.2.2 Bulk relative density of the top and bottom mixes after testing of, the average rut depth portion under the wheel track and of the portion adjacent to the wheel track.

14.2.3 Percent compaction and percent voids of the top and bottom mixes before and after testing at the same locations as in section 14.2.2.

METHOD B - CONSTANT TEMPERATURE MODE (C.T.M.)

15. Test Temperature

15.1 A constant temperature of 60°C is used.

16. W.T.M. Preparation

16.1 Adjust the W.T.M. water level such that the final level is 13 ± 3 mm ($\frac{1}{2} \pm \frac{1}{8}$ in) below the mould surface. Switch on the bath heaters and the circulating pump to maintain the surrounding water temperature at 60°C. Follow the procedure outlined in sections 9.2 and 9.3.

17. Beam Profiles

17.1 Follow the procedure of section 10.1.

18. Beam Conditioning

18.1 After cooling the prepared specimen to room temperature, place the mould assembly in a 60°C air bath overnight or until constant temperature is attained.

19. Test Procedure

19.1 Remove the mould assembly from the air bath and place it in the W.T.M. Secure the mould to eliminate any movement under the action of the wheel. Switch on the infrared lamps and maintain the surface temperature at 60°C.

19.2 Testing may be started when all beam temperatures readings (surface, interface, and base) are at 60 ± 1 °C. Follow the remainder of the procedure as outlined in sections 12.2 to 12.4.

20. Determination of Average Rut

20.1 Follow the procedure of section 13.

21. Report

21.1 Follow the procedure outlined in section 14.